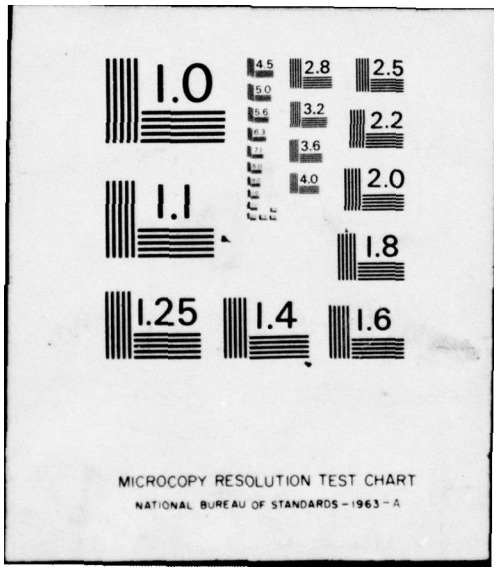
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Primary Selective-Secondary Selective Electrical Distribution System

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The conceptual development and design of a general warehouse module for the Norfolk, Virginia area was accomplished. A life cycle cost analysis was made to furnish the Department of Defense with information to be used in a study of the Service's material distribution system. The design embraced civil, mechanical, and electrical engineering aspects of the facility. Various structural schemes were investigated with regard to feasibility and flexibility within a range of building heights from 30 to 60 feet. Alternative methods

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19. Fire Protection System
Pile Supported Floors
Moment Resisting Foundations
Tilt Slab Walls
Bridge Crane System
High Pressure Sodium Lighting
Freezer/Cooler Area
Roofing
Energy Monitoring and Control System
Heating, Ventilation and Air Conditioning (HVAC) Loads

20. of satisfying energy requirements were analyzed with the aim of maintaining specified internal environmental conditions and accommodating anticipated electrical loads. Design of an associated electrical distribution network and lighting system were included. A comprehensive discussion of fire protection considerations is also presented. The design results and economic analysis indicate: (1) a braced frame steel structure is the most cost effective structural plan, (2) purchased power is cheaper than a total energy system for the projected operating schedule, (3) a primary selective-secondary selective electrical distribution system is required, (4) fire protection costs are a significant factor in the total cost, and (5) a 60 foot facility has the lowest cost per 1000 cubic feet of volume.



A GENERAL WAREHOUSE MODULE

CONCEPTUAL DESIGN AND COST ANALYSIS

(Main Report Text and Appendices)

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CONCEPTUAL DESIGN AND COST ANALYSIS
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of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

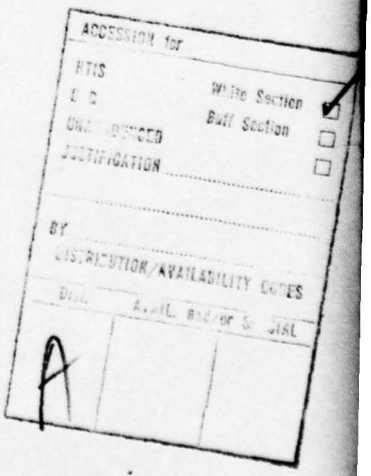
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PREFACE

The Air Force Institute of Technology (AFIT), School of Engineering, Graduate Civil Engineering/Facilities Class of 1976 (GCE-76S) developed a design concept for a general warehouse module as an integral component within the overall mission of the Engineering Analysis Task Group (EATG). The class members who participated in the development of the design concept are all United States Air Force (USAF) officers with the exception of one member who is a Royal Australian Air Force (RAAF) officer. The nine class members are listed below.

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The design study of the general warehouse module was accomplished in partial fulfillment of the requirements for the degree of Master of Science. In producing the design study numerous individuals and organizations provided their time, their valuable technical assistance derived from years of experience in their respective disciplines, and, in many cases, unlimited patience. GCE-76S wishes to express its gratitude and sincere appreciation to all persons who assisted in the development of this conceptual design but the following individuals' efforts were particularly noteworthy.

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In order to recognize a very special member of our "team effort", the entire class desires to acknowledge the persistence and attention to detail of our typist, Mrs. Margaret A. Teague.

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LIST OF ABBREVIATIONS

A	- Amperes
AB	- Absorption
AC	- Alternating current
A/C	- Air conditioning
AFIT	- Air Force Institute of Technology
AHU	- Air handling units
AWG	- American Wire Gauge
Bldg	- Building
BTU	- British Thermal Unit
BTUH	- BTU's per hour
cfm, CFM	- Cubic feet per minute
cu ft, ft^3	- Cubic foot
cu yd	- Cubic yard
D	- Diesel
DC	- Direct current
ΔT	- Temperature differential
^oF	- Degrees Fahrenheit
$/1000 cu ft	- Dollars per 1000 cubic feet
ea	- Each
Elec	- Electric
Equip	- Equipment
FC	- Foot-candles
ft, Ft	- Foot
gal	- Gallons

GEN STOR AREA	- General storage area
gpm, GPM	- Gallons per minute
GT	- Gas turbine
HP	- Horsepower
hr	- Hour
in	- Inch
K	- Effective length coefficient
kip, k	- 1000 pounds
ksi	- Kips per square inch
KVAR, KVA	- 1000 volt amperes
kw, KW	- Kilowatt or 1000 watts
KWH	- Kilowatt-hours
KV	- Kilovolts
lb	- Pound
lf	- Linear foot
MAINT	- Maintenance
Mat	- Material
MBTUH	- 1000 BTU's per hour
MCM	- 1000 circular mils
MECH AREA	- Mechanized area
Mech Room	- Mechanical room
mph	- Miles per hour
MVA	- Million volt amperes
no., #	- Number
PCI	- Pounds per cubic inch
PF	- Power factor

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Φ	- Phase
pH	- Phenophthalein
plf	- Pounds per linear foot
psf	- Pounds per square foot
psi	- Pounds per square inch
psia	- Pounds per square inch absolute
psig	- Pounds per square inch gauge
rpm, RPM	- Revolutions per minute
ST	- Steam turbine
sq ft, ft^2	- Square foot
sq in, in^2	- Square inch
TE	- Total energy
Tons	- 12,000 BTU/hr of cooling (as used in "Internal Energy Systems" chapter)
U	- Coefficient of heat transfer in BTU/hr
V	- Volt
W	- Watt
w/o	- Without
Z	- Impedance in ohms

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ABSTRACT

The conceptual development and design of a general warehouse module for the Norfolk, Virginia area was accomplished. A life cycle cost analysis was made to furnish the Department of Defense with information to be used in a study of the Service's material distribution system. The design embraced civil, mechanical, and electrical engineering aspects of the facility. Various structural schemes were investigated with regard to feasibility and flexibility within a range of building heights from 30 to 60 feet. Alternative methods of satisfying energy requirements were analyzed with the aim of maintaining specified internal environmental conditions and accommodating anticipated electrical loads. Design of an associated electrical distribution network and lighting system were included. A comprehensive discussion of fire protection considerations is also presented. The design results and economic analysis indicate: (1) a braced frame steel structure is the most cost effective structural plan, (2) purchased power is cheaper than a total energy system for the projected operating schedule, (3) a primary selective-secondary selective electrical distribution system is required, (4) fire protection costs are a significant factor in the total cost, and (5) a 60 foot facility has the lowest cost per 1000 cubic feet of volume.

I. Introduction

Background

The Department of Defense Material Distribution System (DODMDS) Study Panel was chartered 25 March 1975. The panel's purpose is to examine the current DODMDS and recommend improvements which will support the Services' requirements effectively and economically in both peacetime and under mobilization. The specific mission of the panel is to review and analyze current material distribution systems processes, and identify future peacetime and mobilization support requirements worldwide. The panel will recommend alternatives to integrate, consolidate, and standardize distribution system functions and facilities within the fifty states where it is beneficial in terms of response and cost.

As one part of the overall mission of the study panel, the Engineering Analysis Task Group (EATG), formerly the Distribution Center Design and Modernization Task Group, is specifically charged with the responsibility of developing an implementation plan for the modernization of existing facilities and/or constructing new supply distribution depots. EATG developed general criteria for a modern modular storage facility with the objective of reducing operating costs. EATG's objectives were presented to the Air Force Institute of Technology (AFIT), School of Engineering, Graduate Civil Engineering Facilities Class of 1976 (GCE-76S) as a possible thesis design project.

Problem

GCE-76S was asked to develop a facility concept for a 50 acre modular warehouse varying in height from 30 to 60 feet. The unobstructed cubic

space from wall to wall and floor to ceiling was to be maximized. The projected cost of construction, operation, and maintenance for each of the proposed systems was to be presented so that a new facility cost could be determined. Nine members of GCE-76S took this problem as a project to satisfy the requirements for a Master of Science degree at AFIT.

Scope

The design of the general warehouse module was based on the conditions at Norfolk, Virginia. Norfolk was one of five possible site selections presented by EATG, and it was selected by the class as being representative in design parameters. This does not imply that Norfolk would remain in the final DODMDS findings.

The facility was subdivided into four major areas; operating, mechanized, general storage, and freezer/cooler. The operating area contained 10 acres for distribution processing. The mechanized area was 10 acres which includes computer controlled mechanized storage and electrical systems. The general storage area consisted of 30 acres of open storage for large and bulk items. The freezer/cooler was a combination facility with one million cubic feet of storage capacity.

Approach

Civil, Electrical, and Mechanical engineering teams were established to accomplish the design study. As an AFIT academic requirement each man of the GCE-76S group served on two of the engineering teams.

The design was accomplished in two phases; conceptual phase and design phase. During the conceptual phase, alternative systems were investigated to determine their feasibility and a projected building shape was determined. Feasible systems were further investigated and final

selections and cost determinations made during the design phase. The following computer programs were used as aids in the final design and analysis:

1. STRESS - Structural analysis
2. ECUBE - Energy analysis and mechanical equipment simulation
3. LOAD-FLOW - Voltage drops determination
4. LGHTECON - Design and economic analysis of lighting systems

The design study was conceptual in nature, therefore, specific design detail was not addressed and no detailed construction drawings were provided. The design did incorporate state-of-the-art in all applicable systems. Hence, current DOD design constraints and policies were not limiting factors in the study. Although allowing for a broad range of missions and ease of future expansion, special function buildings to house such commodities as explosives, ammunition, hazardous chemicals, and radioactive materials were not included.

The costing approach utilized throughout the study was based on 1976 material prices including labor, overhead, and profit where applicable for economic conditions in the Norfolk, Virginia area. Annual costs were derived by amortizing the capital costs over a 25 year economic life, assuming a ten percent interest rate and zero end of life salvage value. Formula 1 was used to determine the capital recovery factor (Grant, 1970:36).

$$A/P = (i(1 + i)^n)/((1 + i)^n - 1) \quad (1)$$

where:

A/P = The capital recovery factor

i = The interest rate

n = The economic life in years

Cost results are presented in annual cost per 1000 cubic feet. The final costs, however, are not comprehensive. Due to the scope and conceptual nature of the design effort, certain areas that would be incorporated in a comprehensive cost analysis were not included. Specific topics not addressed in the cost analysis were:

1. Material handling and processing equipment
2. Personnel support facilities such as offices, toilets, and cafeterias
3. Plumbing, sewerage, and storm drainage
4. Site preparation
5. Land
6. Exterior and interior doors and loading docks

Sequence of Presentation

A structural system evaluation is presented in Chapter II. The detailed evaluation, progression from the development of design criteria to selection of a structural system, culminates in a conceptual design and cost analysis. The electrical and mechanical systems analyses were combined because of their interdependence in evaluating total facility loads. The electrical requirements and design based on various mechanical equipment arrangements is presented in Chapter III. Environmental equipment ranged from a purchased power system to heat reclaim refrigeration associated with an on-site total energy system. The topics of Solar Energy, Energy Monitoring and Control Systems, and the Freezer/Cooler facility are also covered in Chapter III. Chapter IV discusses feasibility and merit of various fire protection systems and fire wall configuration for the four different structural heights. Chapter V presents the conclusions drawn from the study and cost analysis for the structures and supporting environmental systems.

II. CIVIL ENGINEERING

Introduction

The Civil Engineering section of the General Warehouse Module project embraces the design of the building structural frame, roofing and walls, foundations and floor, and a bridge crane system. Because a functional plan and a related physical layout have not been firmly established, a conceptual, rather than a detailed, design approach has been adopted. However, in order to demonstrate feasibility, it has been necessary to include detailed design in some areas.

Functional requirements will almost certainly be a controlling factor in the final selection of a building layout. In addition, the selection of various building heights within the final facility to meet diverse operating situations is conceivable. The aim of the Civil Engineering section, therefore, was to produce a structural scheme which would allow variations in planning and satisfy the functional requirements specified by EATG while achieving an economic and feasible design. All design is limited to state-of-the-art technology, although where innovative techniques have possible application some discussion is included.

Design Approach

To accommodate a range of building concepts, as opposed to a specific design, a rather flexible approach to the study was necessary. The principle design steps listed below represent the core of a process that involved continual iteration and expansion as general concepts were developed. These design steps are repeated sequentially in the report so that the logical elimination or acceptance of the concepts examined

becomes evident. The sequence of presentation is as follows:

1. Definition of the problem and expansion of EATG requirements
2. Evaluation of loads
3. Selection of structural scheme and preliminary design
4. Design of major structural components including:
    a. structural frame
    b. interior walls
    c. exterior walls
    d. roofing
    e. foundations and floor
    f. bridge crane system
    g. secure storage
5. Costing
6. Conclusions
7. Recommendations

In pursuing the design process two over-riding criteria were constantly emphasized. The primary aim was to provide a facility with a minimum life-cycle cost over a 25 year period. The need to provide functional flexibility within the facility and a capability for future expansion also influenced the design.

Problem Statement

The principle criteria for the Civil Engineering study, as defined by EATG, was to provide for a facility covering 50 acres with allowance for building height varying from 30 to 60 feet. EATG required a column spacing of 60 feet in both directions for internal maneuverability as specified in Appendix W-1. However, the operating and secure storage areas

of the facility did not warrant such large column spacings and EATG agreed to reduced spans in these areas.

In addition to dimensional requirements outlined above, a range of floor loadings was also specified from 1,000 psf to 8,000 psf. Provision for suspension of conveyors from the roof was requested and specific design of an overhead bridge crane supporting structure was required.

The building was designed for conditions prevailing in the Norfolk, Virginia area. The probability that a number of similar facilities could be constructed in other areas of the country is also noted. Although some of the general concepts developed for the Norfolk area may apply, the need to fully evaluate the various design parameters as a function of the selected site is emphasized.

The principle objective in designing the total facility was to develop cost data relative to the useable volume of the structure. This method of presenting unit costs was selected so that the information would be consistent with other input costs for the EATG computer model.

Design Parameters

Before proceeding with the structural design it was necessary to establish specific structural loads and other pertinent criteria to be applied to the design of a building in the Norfolk area. The feasibility of various structural schemes was established with respect to fire resistance, span and height, corrosion, and applied loads. Specified design loads provided by TM 5-809-1/AFM 88-3 Chapter 1 and 13 for the Norfolk area are:

1. Snow/live load of 20 psf
2. Wind speeds, to include hurricane conditions, of 105 mph

3. Earthquake loads consistent with zone one classification

Snow loads, as specified, were applied directly in the design. Earthquake loads, being a function of building weight, were treated where required in applicable sections of the report.

Wind Loads. Conversion of wind speed into equivalent loads on a structure can be accomplished by determining the values of static wind pressure. To obtain the values of static wind pressure it is first necessary to calculate the dynamic pressure which is a function of the wind velocity. The dynamic wind pressure is given by Equation (2) (Laursen, 1969:7).

$$q = pv^2/2 \qquad (2)$$

where:

q = The dynamic wind pressure

v = The wind velocity

p = The mass density of the air

For standard air with a unit weight of 0.0765 pounds per cubic foot, Equation (2) reduces to (Laursen, 1969:7):

$$q = 0.00256\ v^2$$

where:

q = The dynamic pressure in pounds per square foot

v = The wind velocity in miles per hour

The static wind pressures on a structure are also dependent on the shape of the structure and the manner in which the structure resists the wind. A convenient way of accounting for this is to apply a shape or drag factor to the value of dynamic pressure obtained from Equation (2). These factors are evaluated from detailed wind studies and tests and are generally presented in tabular form for common structural shapes (Laursen,

1969:9).

The data selected for the design was that specified by the Factory Mutual System Handbook (Factory, 1967:75-3). Using this system, a gust factor is applied to the wind velocity and the factored velocity is then used to enter a table giving horizontal pressure. To obtain the design pressure, the horizontal pressure is multiplied by a recommended shape factor of 1.3 (Factory, 1967:75-20). The resultant horizontal design wind pressure was 42.9 pounds per square foot.

Uplift forces acting on the roof were also estimated using the Factory Mutual System Handbook (Factory, 1967:75-3). For windowless buildings, with few exterior doors normally open, Factory recommends using 50 percent of the horizontal design pressure for the roof uplift pressure (Factory, 1967:75-3). This resulted in a design uplift pressure on the roof of 21.45 pounds per square foot.

Soil Properties. For the design of any structure an important parameter to be considered, not only in the specific design of the foundations but also in the selection of a structural scheme, is the soil on which the structure will be founded. Knowledge of the underground conditions at a site is a prerequisite to the economical design of substructure elements and according to Bowles, "It is doubtful if any major structures are constructed at present without site exploration being undertaken" (Bowles, 1968:111). The importance of specific site information, therefore, cannot be ignored. This engineering study was based upon presumed soil properties for an unspecified site, and the need for accurate and detailed redesign for the selected site should be recognized.

The Atlantic coastal plain, which includes the Norfolk area, consists of sedimentary stratified sands, gravels, clays, and marshy deposits, usually unconsolidated to considerable depth (Gaylord, 1968:5-27). These sediments extend to depths in excess of 17,000 feet and in the Norfolk area exceed 2,000 feet in depth and encompass an area extending inland to the Fall line. The Fall line is a geological demarcation at the edge of the Piedmont plateau which, as an example, passes through Richmond, Virginia (Thornbury, 1967:37).

To gain some idea of specific soil properties encountered in the area, contact was established with the Naval Facilities Command (NAVFAC). Soil bearing capacities were found to vary from less than 500 psf to 4,000 psf and, in some very localized areas, up to 8,000 psf (Nothnagel, 1976). In particular the Sewells' point area, which was a proposed site, yields bearing values in the 500 psf range. It was established, however, that there is an 80 percent probability of finding soils with a bearing capacity of 1,000 psf or greater in the Norfolk, Virginia area (McAndrews, 1976). Based upon this statement, and the lack of specific site information, an allowable soil bearing capacity of 1,000 psf was chosen for design. Other soil properties such as modulus of subgrade reaction were assumed, where necessary, from typical values defined for the soil type indigenous to the area. These properties are discussed in the "Foundations and Floor" section.

Evaluation of Structural Systems

Before proceeding with a design analysis and economic appraisal within the range of design parameters prescribed, a general evaluation of structural systems which would most suitably accommodate the facility was undertaken. Preliminary investigations were directed toward building layout,

structural form, and construction materials selection with a view to establishing building flexibility and economy in the final design. Flexibility within the structural scheme was considered important because of the conceptual nature of the project and the need to accommodate an undefined range of functions. Flexibility was also related to the possibility of stage construction of the facility and to meet future needs for extension. Economy was considered the governing criteria for such a large facility. However, it was recognized that economy in one part of the structure did not necessarily result in overall structural economy. In determining the relative merits of various structural schemes, due consideration was given to their ability to carry the anticipated loadings and to effectively transfer those loads to the poor soils anticipated. Additional factors affecting the selection of structural materials were maintainability, corrosion susceptibility, and state-of-the-art construction methods.

Building Layout. On large structures having multiple bays in both directions, substantial economy can often be realized if the overall structure is a square or nearly square area (Gaylord, 1968:19-49). A square layout affords structural economy in exterior wall length and ensures effectiveness in supporting lateral loads. This aspect was discussed with EATG and a typical floor plan was conjointly selected as shown in Figure 1. The three functional sections delineated in Figure 1 are the operating, mechanized, and general storage areas as agreed to by EATG. The operating area encompasses ten acres with a ceiling height of 30 feet and includes two wings for shipping and receiving. The ten acre mechanized area for automated bin and rack storage is designed for various ceiling heights from 30 feet to 60 feet. Storage of bulk items is accomplished in

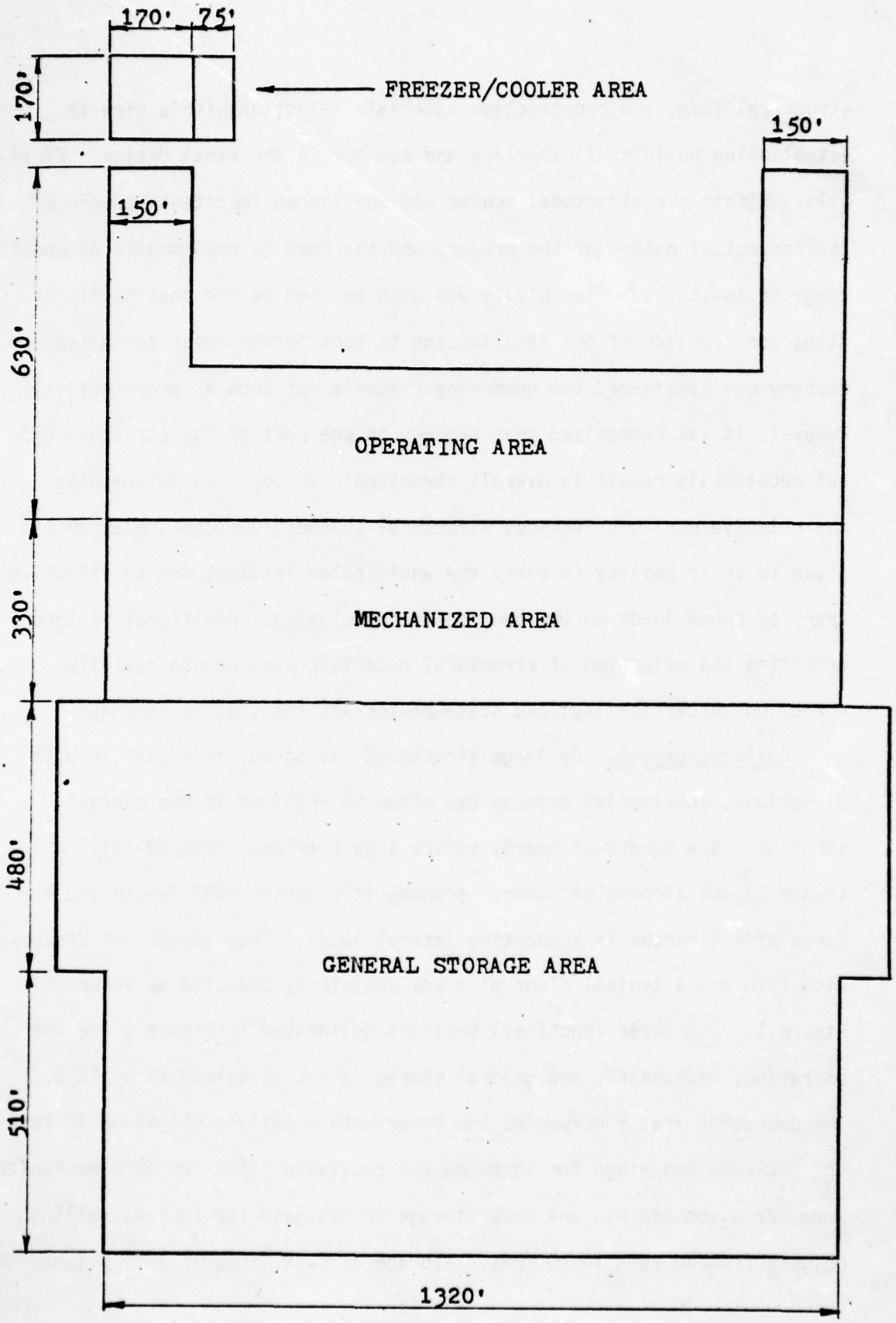


FIGURE 1 BUILDING LAYOUT

the 30 acre general storage area which also has ceiling heights which may vary from 30 feet to 60 feet. Colocated with the warehouse is a 41,650 square foot freezer/cooler facility.

A more specific aspect of building layout was the internal bay design. It was realized that maximum flexibility could be achieved if the building comprised a repetitive series of identical modules. Greatest economy in any structure will be realized when there is as much duplication of the various units and parts as possible. In addition, studies cited by Gaylord show that a square bay design requires the least weight of steel superstructure (Gaylord, 1968:19-50). Thus, in the initial examination of structural systems, emphasis was given to the achievement of a sqaure modular layout.

Structural Form. Various building elevations and structural forms were considered. The proposed building encompasses a large plan area and any deviation from a flat roof profile would result in a significant increase in roofing material requirements. In addition, a flat roof design was considered to allow the most efficient use of available space. This aspect is discussed in more detail in the "Structural Framing" section. A basically flat-roof design was selected for structural economy and better utilization of internal volume.

Structural Materials. The roof system was a major component of the structure because of the long spans involved. Reduction of weight in the roof design would allow use of lighter members in the rest of the structure. Also, any overall reduction in structural weight was desirable so that foundation loads could be minimized. The poor soil in the Norfolk area

could not economically support large foundation loads. Therefore, in examining construction materials, total structural weight was an important factor. Various structural materials were evaluated, including timber, reinforced concrete, prestressed concrete, and steel.

Timber truss roofing systems can be designed to span up to 150 feet, using for example a Howe truss (AITC, 1966:6-20). However, for economical design, the relatively low load carrying capacity of timber generally dictates a short span in the direction perpendicular to the truss system. The allowable extreme fiber stress for timber in tension is in the range of 1000 to 2000 pounds per square inch whereas steel values selected were 30,000 pounds per square inch (AITC, 1966:2-43). To meet the required 60 foot spacing in two perpendicular directions, the truss depth-to-span ratio far exceeds the recommended economic ratio of one-eighth to one-tenth (AITC, 1966:4-79). Timber should only be considered where fire hazard is small and where one bay can be kept to a minimum (Gaylord, 1968:19-57). Based upon this preliminary evaluation, the use of timber for the facility was eliminated.

A reinforced concrete design was undertaken in the preliminary phase. However, standard practice usually limits reinforced concrete spans to less than 40 feet. A simplified analysis of a 30 foot span reinforced concrete beam resulted in a very heavy section when compared to a 60 foot span steel or prestressed concrete design. Because of the desirability of low weight structures in the Norfolk area, reinforced concrete was eliminated for this facility.

A prestressed concrete beam and slab arrangement was designed for the roofing system. Prestressed concrete is an efficient material for long

span systems. However, the gross weight of a prestress concrete building was much larger than in the open web truss design discussed below. Prestressed concrete would result in a costly foundation design. However, it should be noted that a prestressed concrete system may be cost effective if the structure was located in a geographical area in which soil bearing capacities are three to six tons per square foot (Terzhagi, 1967:481). The poor bearing capacity of the Norfolk area soil, and the higher cost of prestressed concrete shown in Appendix C-1, precluded further considerations of prestressed concrete design.

Examination of structural steel design was comprehensive and included consideration of wide flange beam and girder sections, space frames, and open web truss systems. It was evident at an early stage that the use of standard wide flange sections required very heavy members to carry the assumed loads over a 60 foot span. Preliminary cost analysis, included in Appendix C-1, showed this system to be uneconomical.

The feasibility of using a three dimensional truss, or space frame system, was also investigated. Two such systems, available from Unistrut, were analyzed using technical data and costs provided by the manufacturer. The use of a space frame system had the advantage of providing a superstructure which could sustain considerable bomb damage without total collapse. However, an economic analysis of both space frame systems considered, resulted in a higher total cost than for the open web truss system. A summary of relevant cost data for these systems is included in Appendix C-1.

The preliminary analysis of open web truss systems resulted in relatively low weight major beams of from 60 to 80 pounds per linear foot. Trusses

investigated included Pratt, Howe, and Warren designs for a flat-roof and the Fink truss for a sloped roof system. The Warren type truss was selected for efficient use of material in the superstructure design. Rigorous design of the structural system is discussed in the "Structural Analysis" section and cost comparisons of the various structural materials analyzed is shown in Appendix C-1.

Structural Scheme. Evaluation of the feasibility of various systems, as presented above, resulted in the selection of a structural scheme as follows:

1. The primary structural framing material is to be steel.
2. The structural framing is to comprise an open web truss roof system, supported on steel columns.
3. The structure is to be composed of series of similar square or nearly square modules.
4. The overall building is to be approximately square in plan.

Two further criteria investigated in the selection of a structural scheme were the ability of the structure to accommodate wind forces and the provision in the structural form for incorporating adequate roof drainage. Various methods of carrying wind load were evaluated and these are discussed in detail in the "Structural Framing" section of the report. The ability of this structural scheme to carry wind loads was verified.

To provide roof drainage, either a reasonably flat roof using minimum drainage slopes or a high pitched roof providing rapid run-off could be used. A fink truss with a 30 degree slope was evaluated and an approximate truss weight of 65.6 pounds per linear foot was obtained. The Fink

truss system had several major disadvantages. The inclined roof area represented an increase of 15.5 percent over a flat roof area. The lighting design would be adversely affected by the large roof slopes due to the variation in room cavity ratio. Approximately 44 percent more unuseable volume is enclosed within a Fink truss than in a Warren type truss. Considering these disadvantages a flat roof design using a Warren type truss configuration was selected.

Structural Analysis. The computer program STRESS was utilized to facilitate the analysis of all indeterminate structural frames. STRESS, which is the acronym for Structural Engineering Systems Solver, is a programming system for the solution of structural engineering problems utilizing a digital computer and the stiffness (displacement) method. The program is presently written to perform a linear analysis of elastic, statically loaded, framed structures. STRESS solves a set of simultaneous equations relating the unknown joint displacement components to the known unbalanced force components at each joint. Program input consists of the makeup and orientation of all members, and the magnitude, type, and location of all displacements, distortions, and loads. Output includes the joint displacements, member distortions, member end forces, and reactions of a structure (Fenves, 1964).

Structural Framing

The statement of work as presented by the EATG requested that a structural system be investigated that would allow for clear spans in both directions varying in dimension from 60 to 120 feet. These large clear spans were requested for ease of maneuvering long vehicles which would be stored in the warehouse. A preliminary investigation of variation

in structural steel weight with bay area indicated, a 120 by 120 foot bay would be twice as heavy as a 60 by 60 foot bay (Gaylord, 1968:19-5). GCE-76S suggested to EATG that a thorough investigation be made of the 60 foot by 60 foot clear span system. EATG agreed that this would meet all requirements for maneuvering and storage configuration flexibility (Appendix W-1).

Assumptions. The assumptions associated with the structural system are as follows:

1. Roof trusses were analyzed as plane frames using the STRESS computer program. A configuration of four trusses and five columns was chosen as being representative of the continuous system that would be actually constructed.
2. A cartesian coordinate system was chosen such that the x-axis was parallel to the horizontal plane, the y-axis parallel to the vertical plane, and the z-axis perpendicular to the plane of the frame.
3. When the frames were analyzed it was assumed there would be no lateral movement in the z direction because all forces were applied in the plane of the frame. There was however, moment about the z-axis.
4. All joints and column connections were assumed to be fixed except those that were specifically designed and analyzed as pin connected.
5. The uniform live loads were assumed to act perpendicular to the roof surface.
6. EATG specified an 1800 pound conveyor point load every 10 feet in both directions be suspended from the ceiling of the operating

area (Vrba, 1976). This load was converted to an equivalent uniform load of 18 psf to be distributed over the entire operating area to accommodate location of conveyors anywhere within this portion of the facility.

7. A-36 steel was used for column design since the slenderness ratio of most columns was greater than the vertical ratio for inelastic theory. Fy 50 steel was used for framing, bracing, and open web joists. This allowed a reduction in member weights for the large truss spans.

Load Development. The only specified roof load was for the operations area. EATG requested that the roof framing system be capable of supporting a conveyor load of 180 pounds per linear foot supported every ten feet in both directions. This would provide the maximum flexibility for future arrangement of the operations area. The rest of the roof loads were initially assumed as follows:

Snow	20.0 psf
Wind Loads	
Horizontal	42.9 psf
Vertical	21.45 psf
Piping and Ducting	2.0 psf
Roofing and Deck	8.0 psf (Carrier, 1972:1-71)
Open Web Joist	2.0 psf (Grinter, 1960:284)
Secondary Frame	4.0 psf (Grinter, 1960:284)

The final design of the frames was accomplished with a revised set of loads resulting from this study as follows:

Snow	20.0 psf
Wind Loads	
Horizontal	42.9 psf
Vertical	21.45 psf
Piping and Ducting	2.0 psf
Roofing and Deck	10.2 psf
Open Web Joist	
Operating Area	0.78 psf
Mechanized Area	1.20 psf
General Storage Area	1.20 psf
Secondary Frame	
Operating Area	2.66 psf
Mechanized Area	1.6 psf
General Storage Area	1.6 psf

Load Application. Two loading conditions were applied to all portions of the structure.

1. Loading 1 - Dead load of the structure plus snow/live load. In the operating area the load of the conveyor was also added.
2. Loading 2 - The vertical dead and live loads of Loading 1 minus the snow load were combined with a horizontal and suction force resulting from the 105 mph wind.

The previous graduate Civil Engineering Class (GCE-75D) had investigated a large roof area using three loading conditions, two of which were the same as stated above. The third condition was with the design wind forces and one half of the snow load on the roof. Investigation showed that application of partial snow live load reduced the resultant uplift force

and was not as critical as loading condition 2.

Controlling Factors. The horizontal deflection at the top of the column due to wind forces was a limiting factor. Permissible deflections are usually quoted in terms of span. Long standing rules of thumb are limitations of 1/150 to 1/180 of the span for visibly perceptible curvature, and 1/240 to 1/360 of the span for curvatures likely to fracture applied finishes (Gaylord, 1968:19-6). Painting will be the only applied finish within the structure, therefore, an allowable deflection of 1/200 of the span was selected. The allowable deflection is compatible with the movement capacity of the selected roof expansion joints.

Due to the clear span and unobstructed floor to ceiling requirement, diagonal wind bracing within the interior of the structure could not be used.

To provide for the maximum future flexibility the interior fire walls were not designed as shear walls. The fire walls may be removed if required by future facility alterations.

The continuous frame required a thermal expansion joint at approximately 240 foot intervals (Gaylord, 1968:19-53). An expansion joint was also required between the flexible roof system and the rigid fire walls. The expansion joint at the fire wall would serve two functions. It would allow for the thermal expansion and contraction of the structural system and provide flexible connection required to accommodate the sidesway resulting from wind loading.

Selected Approach. The original concept was to design a Warren truss supported on columns and to span the 60 feet between the trusses with standard open web joists. However, when the spans exceed 70 feet in both

directions of a bay, the designer should investigate the use of primary trusses in one direction with secondary trusses framing between them (Gaylord, 1968:19-53). Using a secondary Warren truss at 30 foot intervals along the main truss allowed the use of 30 foot joists. This arrangement resulted in an overall weight and cost reduction for the 60 foot by 60 foot bays when compared to main trusses in both directions and 60 foot joists. A plan view is provided in Figure 2.

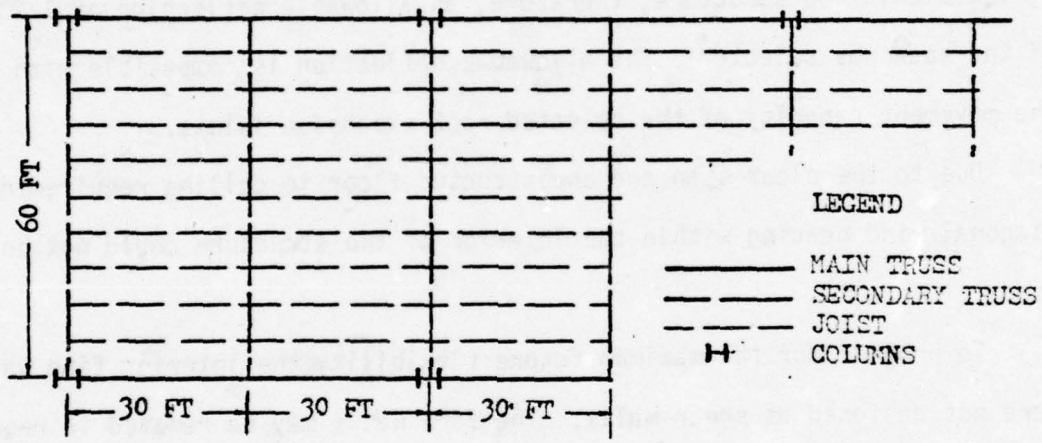


FIGURE 2 PLAN VIEW OF TRUSS AND JOIST SYSTEM

A six foot deep main Warren truss was designed based on the truss height of between 0.08 and 0.12 of the length (Gaylord, 1968:19-53). Web member connection spacing was selected between 1.6 and 2.4 of the frame height (Gaylord, 1968:19-53). The angle between the chords and the web members was chosen as 45 degrees. A single concentrated mid-span load was applied by the secondary truss. The truss was analyzed as pin connected and standard members were selected from the AISC tables to withstand the calculated axial forces.

The secondary truss was designed in a similar manner. The depth was reduced to three feet and the angle between the chords and web members maintained at 45 degrees to provide adequate bracing for open web joists spaced six feet center to center. The joist spacing was chosen based on the support requirement for 20 gauge metal roof decking. The resulting structure will extend six feet above the specified clear height. The specified height is the interior floor to ceiling clear span. Thus the specified height is the interior floor to ceiling clear span. Thus the 30 foot building is actually 36 feet from floor to roof.

Preliminary Plane Frame. The preliminary members of the truss and Loading 1 were entered into the STRESS program. To develop a representative structural model, four bays, each 60 feet long, and five columns were analyzed as a plane frame.

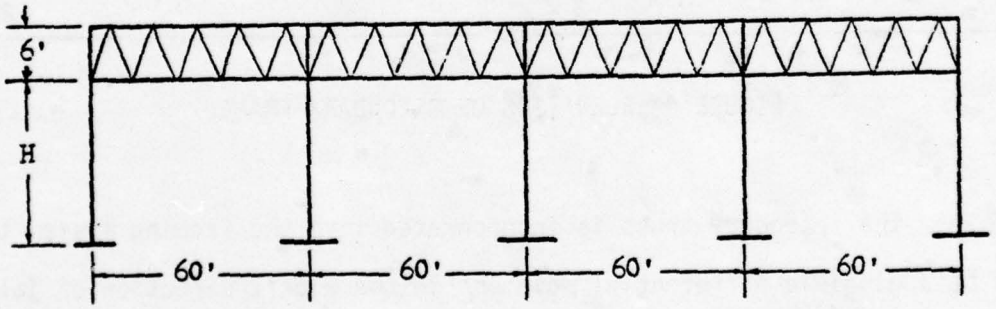


FIGURE 3 FOUR BAY PLANE FRAME STRESS MODEL

Joints that are fabricated by welding or with high strength bolts can transmit moment. Such a joint is more correctly classified as fixed as compared to the theoretical pinned joint. In reality the structure would be a braced frame. The frame analysis introduced moment into the

members which had to be evaluated using the combined force equations provided by AISC (AISC, 1973:5-22). Member analysis and selection was continued until all members met the AISC requirements. For ease of fabrication the top and bottom chords were selected as continuous, constant cross section members. For preliminary analysis all web members were assumed to have the same cross section. Before proceeding with detailed analysis of the main frame, the secondary truss was evaluated using STRESS to give accurate loading information.

The secondary truss was analyzed using both loadings 1 and 2 and a single plane frame model as shown in Figure 4.

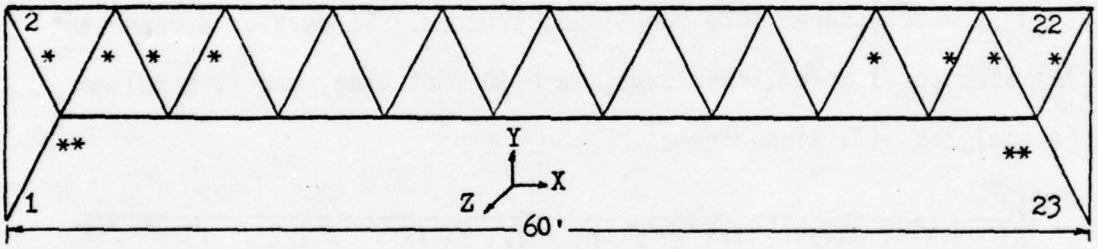


FIGURE 4 ELEVATION OF SECONDARY FRAME

When the secondary truss is incorporated into the framing system there will be negligible differential movement in the x or z direction of joints 1, 2, 22, or 23. Joints 2 and 22 were assumed to be fixed in all three degrees of freedom. Joints 1 and 23 were allowed to displace in the y direction. Based on the model assumption, the design of the secondary truss was completed at this phase of the project. Members were selected that met the maximum combined loading requirements.

TABLE 1

SECONDARY FRAME MEMBERS

Top Chord	6X4X5/16	Double Angle	4 In Legs Together
Bottom Chord	3-1/2X3X3/8	Double Angle	3 In Legs Together
Web Members			
Unstarred	2X2X3/8	Single Angle	
Starred *	3-1/2X3-1/2X3/8	Single Angle	
Brace **	3-1/2X3-1/2X3/8	Double Angle	
Vertical	3-1/2X3-1/2X3/8	Single Angle	

Using this secondary truss and the preliminary main frame, design for wind loading and roof drainage for the overall framing system was investigated.

Roof Drainage. A minimum slope of 1/4 inch in a foot or 15 inches in 60 feet was required for the selected roofing system. The roof was divided into a drainage area 120 feet by 120 feet sloped toward a depressed center. The difference in elevation between the perimeter and center was 22 inches. This required that every second main frame must have a sloped top chord.

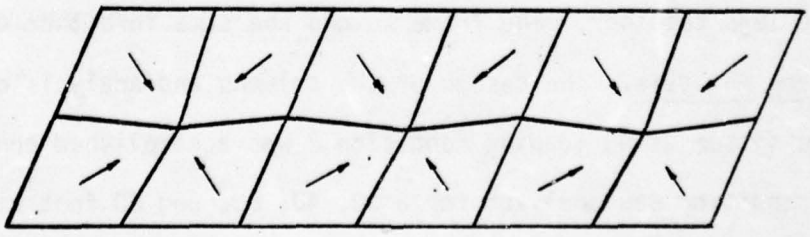


FIGURE 5 ROOF DRAINAGE PATTERN

Sloped Main Frame. The exterior level frame members and columns were put into the exterior sloped frame, four bay STRESS model and anlyzed. All members met the combined stress and deflection requirements. This completes the design of the exterior columns and sloped frame (see Appendix C-2).

GCE-76S realized that all members of the exterior truss would not be loaded to capacity when used as an interior truss. The relative position of the frame member is vital to the STRESS program. The member's moment of inertia is used by STRESS to compute the member stiffness matrix which in the matrix analysis is used to calculate the force in the member. For example, with the long legs together the 6X4X3/8 double angles used in the frame chord have a moment of inertia equal to 26.9 in^4. When this frame is analyzed using wind loading the combined maximum compressive force and moment applied upon the members is within the AISC allowable. However, if the short legs are together the moment of inertia is only 9.81 in^4. A wind analysis of this frame shows the resulting forces are larger and some members are over-stressed. A frame designed with the short legs of the angle together will support the loading in the interior section. The members of such a frame are efficiently loaded. For economy of fabrication and ease of erection all main frames were designed with the long angle legs together. The frame weighs the same in either case.

Total Frame Analysis. The design of the columns and analysis of a four bay frame system using loading condition 2 was accomplished concurrently. Each loading condition was analyzed for a 30, 40, 50, and 60 foot high structure. Initially the horizontal wind force of 42.9 psf was assumed to be uniformly distributed between the main exterior columns. A horizontal

force resulting from a 60 foot wide loading area was uniformly applied to the main frame at each secondary frame location. The fire columns were assumed fixed at the foundation. The STRESS analysis revealed a moment of 1484.1 foot-kips at the wall column foundation. A moment that large could not be accommodated by an economical foundation scheme.

Several proposals were investigated to reduce the moments produced by wind loading.

1. Stiffened Frame. Stiffening of the structure was investigated by incorporating additional columns at 30 foot intervals along the perimeter and within the first perimeter bay as shown in Figure 6. The moment at the exterior foundation was reduced to 708 foot-kips which was still considered too large.

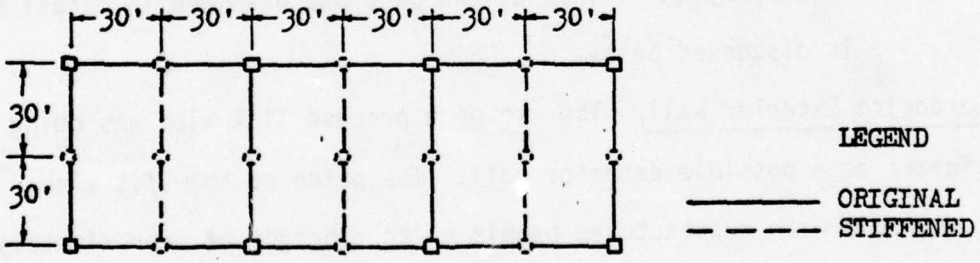


FIGURE 6 PROPOSED EXTERIOR BY STIFFENING

2. Guy Cable. The installation of a guy cable at an angle of 45 degrees from horizontal, attached to the top of the 60 foot column and anchored to a retaining block, was investigated. A model was examined with the exterior column connection assumed pinned at the base. It was determined that column moments on the four-bay model ranged from 161 to 117 foot-kips.

However, this system presented two major objections. The cables placed every 60 feet around the perimeter would restrict exterior traffic flow. Also, the cables would require maintenance both from a corrosion and tension standpoint. The life cycle cost of a guy cable system would be considerable.

3. Cantilever Wall. The use of a continuous cantilevered exterior wall was considered. This system would carry part of the wind load along the entire length of the perimeter rather than at discrete column points and eliminate the obstructions from the use of guy cables. Preliminary evaluation showed that this system would result in smaller column footing moments in the four-bay model. The use of a concrete or masonry wall fixed at the base was examined in detail and is discussed below.

Composite Exterior Wall. The use of a precast lift slab was being investigated as a possible exterior wall. The price of the lift slabs were comparable with manufactured panels up to a height of approximately 25 feet. A design was investigated using a cantilever tilt slab wall up to 20 feet and a manufactured panel wall from 20 feet to the roof. The wall wind loading condition was also redesigned. Two intermediate "stub" columns, assumed to be pinned at the top and bottom, were incorporated equally spaced between the main columns in the wall plane. The main column in the plane of the wall was assumed to be pinned at the base. The wind loading area per column would be effectively reduced to a 20 foot wide strip if the wall had uniform stiffness. A conservative loading

scheme was adopted that distributed a uniform load to the wall column equal to a 30 foot wide strip from the top of the concrete wall to the roof. A horizontal force amounting to one half the force from a loading area 40 feet wide extending from the concrete wall to the roof was applied to the mid-point of the main frame in the exterior bay. This loading was assumed to comprise the forces at the top of the pin connected stub columns transmitted into the main frame through the stiffness of the metal roof decking, joists, and secondary frame. This proposal would provide a secure exterior wall that would be maintenance free. The revised wind load application more correctly models the force distribution.

Wind Stress Analysis and Design. A four bay perimeter section, 240 feet wide, was selected to dissipate wind forces around the facility. Within this section the longitudinal axis of the main frame is perpendicular to the exterior wall. The wind forces are totally dissipated within these four bays through the foundations. This configuration eliminated all but wind uplift forces in the interior of the facility. Further detail of this system is included in the following section on column design.

Column Designation. There are four column designations for each building height: interior, exterior, stub, and box. The interior and exterior columns are standard wide flange sections. At the corners of the structure the maximum wind force can occur normal to either wall face. A box column design was used to provide adequate resistance to both possible maximum wind conditions at the corners. The stub columns are intermediate pinned members between the main columns along the perimeter wall. Figure 7 illustrates column and footing designations and locations.

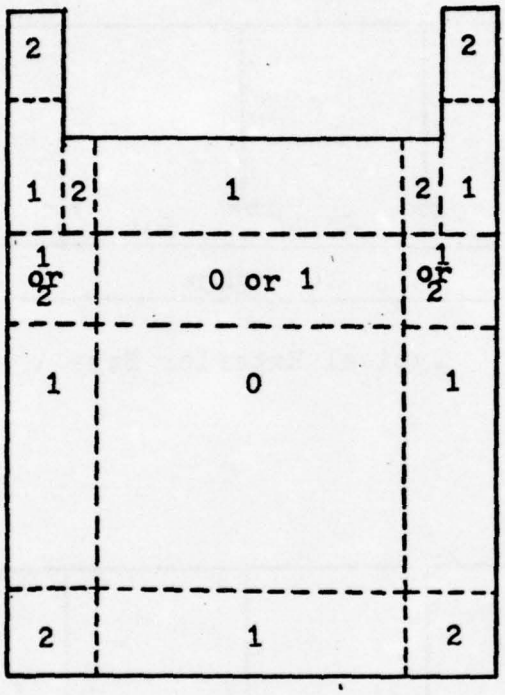
1. Exterior Column Design. Design boundary conditions for the

columns are shown in Figure 8. It was assumed that these conditions could be feasibly constructed. The value of K was chosen as 1.0 (AISC, 1973:5-138). The initial exterior column selection was based on a simplifying assumption that the horizontal wind shear could be equally divided among the five columns in an exterior main frame. A column was then analyzed as a fixed end beam carrying a uniform load. The fixed end moments were calculated and a member selected by interpolating the AISC beam tables. The newly selected exterior columns, the preliminary frame members, and the composite exterior wall wind loading was programmed into a level, four bay STRESS model. The wind loading proved to be the most severe loading condition. Several iterations were required to bring all the structural members into compliance with the combined axial compression, bending stress restrictions (AISC, 1973:5-22) and deflection limits. This completed the design of the exterior column and the exterior level main frame.

TABLE 2

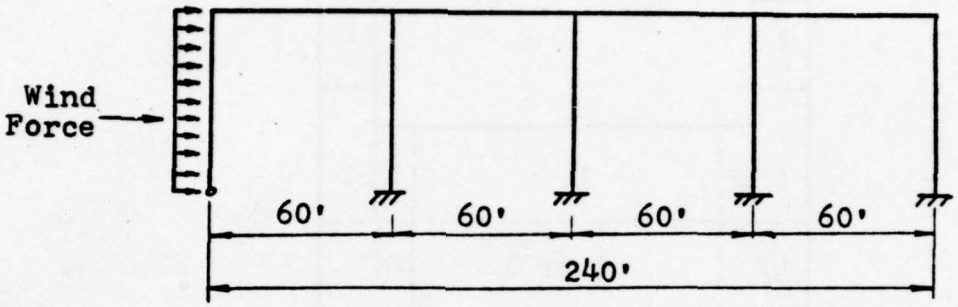
LEVEL AND SLOPED MAIN FRAME MEMBERS

Top Chord	6X4X3/8	Double Angle	6 In Legs Together
Bottom Chord	6X4X7/16	Double Angle	6 In Legs Together
Web Members	5X3X3/8	Single Angle	5 In Leg Out

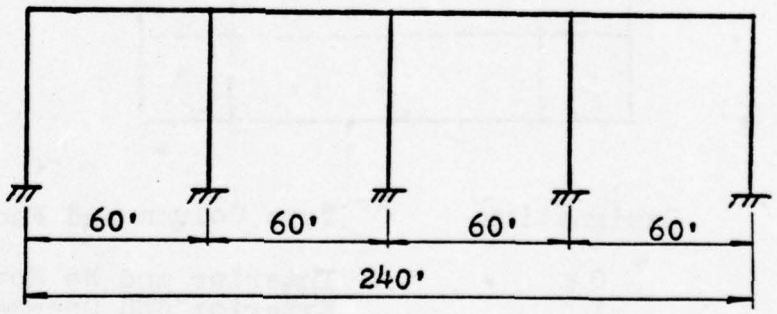


Designation	Type Column and Footing
0	Interior and No Moment
1	Exterior and One-Way Moment
2	Box and Two-Way Moment

FIGURE 7 ILLUSTRATION OF TYPE COLUMN AND FOOTING LAYOUT



Typical Exterior Bays



Typical Interior Bays

FIGURE 8 TYPICAL EXTERIOR AND INTERIOR BAYS

TABLE 3

EXTERIOR COLUMNS

Height	30 Ft	40 Ft	50 Ft	60 Ft
Size	W14X84	W21X127	W27X145	W33X152

2. Box Column Design. Due to the wind uplift the columns were acting more as uniformly loaded beams than as columns. The deflection at the top of the column was the controlling factor and not the unit stress. As a result the box columns were designed as beams with a moment of inertia for both axes equal to the strong axis moment of inertia of the acceptable exterior columns. The selected box sides were checked for local buckling. The box columns were modeled in the four bay STRESS program. The analyzed forces meet the combined stress and deflection criteria (see Appendix C-2).

TABLE 4

BOX COLUMNS

Height	30 Ft	40 Ft	50 Ft	60 Ft
Size (In)	12X12X11/16	20X20X5/8	22X22X3/4	25X25X3/4

3. Interior Columns. The worst loading condition for interior columns was Loading 1. Interior column loads were constant for all building heights. The most critical factor in the design of all columns was the selection of a realistic

effective length. For this analysis the interior sections of the building were assumed to act as braced frames. Basically, a braced frame is one in which sidesway buckling is prevented by bracing elements of the structure other than the structural frame under analysis (Salmon, 1971:785). For a column with fixed connections at top and bottom, the theoretical value of K is 0.5 and the recommended value is K = 0.65. As fixity cannot be guaranteed in structural framing of the type used, a margin of safety of approximately eight percent was added to give a K value of 0.70. Using this value of K and an axial load of 141 kips, 30 foot, 40 foot, and 50 foot columns were selected using the AISC column tables. Suitable tabular data was not available for the 60 foot column and this column was designed as shown in Appendix C-2. The selected columns and the exterior frame were modeled in the four bay STRESS program using both loading conditions. All members were acceptable. A summary of column details is included in Table 5.

TABLE 5

INTERIOR COLUMNS

Height	30 Ft	40 Ft	50 Ft	60 Ft
Size	W12X53	W10X60	W14X78	W12X92

Stub Columns. Intermediate columns were required at 20 foot

intervals around the building perimeter to support wall panels. These columns, called stub columns, were also capable of absorbing part of the wind load in shear at the base. Stub columns were designed to be pinned at both ends. The wall load on these columns was small and the more critical design load was due to wind. Therefore, these columns were designed as beams uniformly loaded over part of their length. Typical design calculations are shown at Appendix C-2. The column properties are summarized in Table 6.

TABLE 6

STUB COLUMNS

Height	30 Ft	40 Ft	50 Ft	60 Ft
Size	W8X20	W12X36	W16X50	W21X68

Operating Area. The operating area will be a 30 foot high structure. However, additional structural load capacity was required to accommodate proposed roof supported conveyor systems. A configuration was selected that would incorporate the previously designed main and secondary frames. Spacing of the frames was a function of the conveyor loads.

1. Load Development. The loads developed by GCE-76S were combined with the conveyor loads given by EATG. The 180 plf was made up of a live load of 150 plf and a dead load of 30 plf (Vrba, 1976). A 25 percent impact factor was applied to the live load and the entire load was uniformly distributed over a 100 square foot loading area (AISC, 1973:5-13). It must be

noted that the columns, main and secondary frames are the only structures that are being designed to carry the conveyor loads. When the conveyors are installed additional structural members will have to be installed at ten foot intervals to support the actual conveyor. It is not economically feasible to design all joists to be capable of indiscriminately supporting an additional 1800 pound point load.

2. Analysis. In the general storage and mechanized areas the secondary frames were spaced 30 feet apart to support point loads of 6.76 kips at six foot centers. The spacing on the secondary frames in the operating area was changed to 18 feet and new joists selected. The resulting joist loads were 6.10 kips with joists spaced six feet center to center. The existing secondary frame was used to accommodate this loading situation. The new connection of the secondary frame into the main frame is in the same relative position as with the 30 foot spacing. The main frame was initially designed to support a secondary frame load of 61.65 kips at 30 foot spacing. With 18 foot spacings the new secondary frame loading for the operating area is 61.0 kips. The column spacing for the main frame was reduced from 60 feet to 36 feet. The original 30 foot long columns, spaced at 60 foot intervals, had an axial load of 126.0 kips. The axial column load for 36 foot spacings was 123.8 kips. The resulting frame system will provide the operating area with a 36 by 60 foot column spacing and complete flexibility for roof mounted conveyor

systems.

Cost Analysis. The cost of the structural steel system is dependent on the number and location of fire walls. The National Fire Code required the steel structure to be terminated at each fire wall. If a fire wall is located along a proposed column line then one additional set of columns and frames is required adjacent to the fire wall. However, if the fire wall is located between proposed column lines, two additional sets of columns and frames are required along the fire wall to terminate the steel structure.

The cost analysis presented below was developed assuming there were no interior walls in the facility other than the walls separating the operating, mechanized, and general storage areas. The structural members required to accommodate these walls have been included in the estimate. A development of the costs for the additional steel required with fire walls enclosing 80,000 square foot areas is presented in the "Interior Walls" section.

The cost per ton of steel used in this study was developed from Means 1976 based on the Washington, D.C. price schedule. The price included fabrication, transportation, erection, additions for long sections, and painting. A complete quantity estimate and unit price schedule is contained in Appendix C-2.

TABLE 7

ESTIMATED COST OF STRUCTURAL STEEL

($/1000 CU FT)

LOCATION	BUILDING HEIGHT (FT)			
	30	40	50	60
Operating Area	106.64	-----	-----	-----
Train Sheds	61.67	-----	-----	-----
General Storage	81.11	69.07	62.40	57.90
Mechanized	88.35	78.90	73.78	70.19

Interior Walls

Clear ceiling heights of 30 to 60 feet were investigated in increments of ten feet. Nonbearing interior wall sections, to be used as fire walls, were investigated for the four ceiling heights. The roof frame was six feet deep. A three foot high parapet was provided over all interior walls for fire protection. Interior walls were 39 to 69 feet high, varying in increments of ten feet.

Loads. The general warehouse module analyzed was located in seismic zone one. The minimum lateral force to be applied in the design of an interior wall was ten pounds per square foot (AFM 88-3, 1973:4-2). Hurricane force winds were used in computing the force that was applied on the parapet. These two forces were greater than the seismic forces for the respective sections in both cases (Appendix C-3). No live load was carried by the interior walls. The dead load on the walls was only the weight of the wall materials (Appendix C-3).

Materials. A reinforced concrete masonry wall was selected for the design. This decision was influenced by the minimum thickness required for the heights investigated (Appendix C-3). The fire resistive rating was six hours (Factory, 1967:7-2).

Wall Support. Several wall cross sections were investigated. The design procedure utilized was an iterative process (Appendix C-3). The wall was placed along existing column lines, where possible, to gain maximum utilization of space in the warehouse (Appendix C-3). A fire wall should have the ability to remain in place if, due to fire, the building frame collapses on one side of the wall. A freestanding wall easily meets this criteria. Thickness of freestanding walls was twice that

of a wall with support along the top. High freestanding walls were found to have limited lateral stability and were avoided due to the difficulty and expense of providing lateral stability (Factory, 1967:7-4).

A tied wall design derives its structural stability from the building frame. This design is not recommended near expansion joints in the frame (Factory, 1967:7-3). In these areas a freestanding wall or double wall must be used, or the frame must be modified to make it continuous (Factory, 1967:7-3). The walls were designed assuming fire areas as discussed in the "Fire Protection" section of this report. Double walls were used along three wall lines. These walls were opposite the building exterior walls. Each wall of the double walls was tied to the frame adjacent to the walls. The remaining interior walls were supported at the roof level by the frame system. Self releasing steel members that slide away from the wall as the frame collapses were used (Factory, 1967:7-4). These were used on both sides of the wall. This placed no lateral pull on the wall during frame collapse. Lateral stability was gained in both directions.

Footings adequately supported some of the selected wall designs on the soil conditions assumed at Norfolk. Piles were required for the support of the other selected designs (Appendix C-3).

Costs. The wall costs do not include the price of doors. No information was made available to GCE-76S as to the height and width requirements for door openings. Numbers and size of conveyor openings were not known. Rather than assuming impractical values, the wall was assumed to be solid when cost data was calculated. The appendix lists the wall costs in dollars per 100 linear feet of wall, in addition to dollars per 1000 cubic feet of storage space.

TABLE 8

INTERIOR WALLS

Building Clear Height (Feet)	30	40	50	60
Wall Height (Feet)	39	49	59	69
Cost ($ Per 1000 Cubic Feet)	49.91	56.28	61.70	63.69

Exterior Walls

In designing the exterior walls for the facility, several criteria were established. This section discusses these criteria and lists the alternative designs considered. The final design is discussed and its associated cost data is presented.

Design Criteria. In designing the exterior walls, it was determined the final design would have to meet the following criteria:

1. Because of the large design wind load coupled with the poor soil conditions, the exterior wall would have to provide a means of reducing the wind loads that are transferred to the columns and the column footings.
2. The exterior wall U value specified in the "HVAC Loads" section of this report was 0.10.
3. Flexibility was another important criteria. To accommodate future expansion and structural changes such as the addition of loading doors, the exterior wall would have to be non load bearing and easily disassembled.
4. The exterior wall would have to be durable. Both the interior and exterior side of the wall would be located in high activity areas, thus subject to bumping by trucks and forklifts.
5. It is desirable that the exterior wall provide a certain degree of building security. The wall must be puncture proof so as not to allow easy entry.
6. Since the facility is being designed for a highly corrosive environment, the exterior wall would have to resist corrosion.
7. The exterior wall must be economically feasible. Ease of

construction and the cost of material must be considered. The design must fall within "state of the art" technology.

Design Alternatives and Selection. In order to meet the design criteria several alternative designs were considered. These design alternatives will be discussed in detail.

A steel sandwich panel exterior wall, consisting of an exterior siding, two inches of insulation, and an interior liner, was investigated. The group investigated using factory assembled panels as an alternative to field assembled wall panels. The field assembled siding was ruled out because the cost was significantly higher than the factory assembled siding. The sandwich panels were able to meet the design U value of 0.10 and proved to be the least expensive of the alternatives considered. However, they were determined to be unsatisfactory for several reasons. The sandwich panels could not effectively reduce the wind load taken by the columns. The steel did not provide adequate building security in that access to the building could be gained by simply puncturing the wall. In addition, the exterior of the steel sandwich panels would be subject to corrosion in high activity areas such as around loading doors, where the protective coating would be scratched. The interior portion of the steel sandwich panel would not be durable enough to withstand bumping by fork lifts.

An aluminum sandwich panel exterior wall consisting of an aluminum exterior panel, two inches of insulation, and an aluminum interior panel was investigated. The design U value of 0.10 could be obtained but the cost of the aluminum was significantly higher than the steel sandwich panel. The aluminum panel had a higher resistance to corrosion than the steel. As with steel sandwich panels, the aluminum panels could not be constructed

to reduce the wind load taken by the columns, would not provide adequate building security, and would not be durable enough to withstand bumping by trucks and fork lifts.

Masonry walls were also considered. It is possible for the masonry walls to be constructed so as to take a portion of the wind load from the columns. The masonry wall can meet the design U value of 0.10 by adding insulation and an interior steel panel, plus provide adequate security and durability. One major drawback to the masonry wall was the high cost of construction, especially at the higher building heights. In addition, a masonry exterior wall would not meet the flexibility criteria. If future expansion were to be required the wall would have to be torn down and reconstructed rather than disassembled.

Tilt slab exterior walls were also considered. The tilt slab involves pouring the wall section on the floor, over a bond breaker, then lifting the wall sections into place. The tilt slab can be anchored to the foundation to aid the columns in resisting the wind load. They are durable and provide adequate security. In addition, the tilt slab does meet the flexibility criteria in that the sections can be disassembled and moved if the building were to expand. The cost of tilt slab is competitive with steel sandwich panel up to a height of 20 feet; however, at heights above 20 feet the costs increase significantly.

Since no one material met all of the design criteria, it was necessary to investigate additional alternatives. The alternatives considered were to use either a masonry wall or a tilt slab up to a certain height, then use steel sandwich panels for the exterior wall above this height. When considering these additional alternatives, only the tilt slab with the steel

sandwich panels met all of the design criteria. It was more economical than the masonry/steel sandwich wall. The tilt slab portion of the wall would be durable and provide adequate security. Tilt slab would not corrode. Since the steel sandwich panel would be above the activity areas there would be less chance for scratches; therefore, less chance for corrosion to occur. Both the steel sandwich panel and the tilt slab wall could be disassembled in the event the facility were to expand.

The cost of the tilt slab increases with height. At lower heights tilt slab is more economical than the steel sandwich panel. For larger heights the tilt slab is more expensive. The tilt slab was carried up to a height of 20 feet. At this point the cost of the tilt slab did not exceed the cost of the steel sandwich panel. The 20 foot height of tilt slab also allowed for a decrease in the amount of moment transferred to the column footing.

It was estimated the tilt slab would be 7-1/2 inches thick. To obtain a U value of 0.10, 1-1/2 inches of rigid fiber glass insulation would be installed on the interior surface (ASHRAE, 1972a:361). Steel siding would be added to the interior to protect the insulation. See Figure 9 for a cross section of the tilt slab portion of the wall.

An important function of the tilt slab portion of the wall is to reduce the wind load taken by the exterior columns. In order to accomplish this, the tilt slab must be rigidly connected to the foundation pedestal. The maximum wind force that must be resisted by the base of the wall is 8.58 kips per linear foot. One method of insuring a rigid connection and maintaining flexibility is shown in Figure 12. The 8.58 kips per linear foot force can be adequately resisted by using 3/4 inch diameter, 40 ksi steel

bolts embedded in concrete at one foot intervals. These bolts would also resist the resultant shear loads and the required embedment length is available in the pedestal.

The steel sandwich portion of the wall would consist of an exterior 20 gauge steel panel, two inches of insulation and an interior steel liner. Figure 10 shows the cross section of the steel sandwich panel. The sandwich panel would be connected to horizontal girts, spaced eight feet apart. The exterior panel could take a maximum allowable load of 53 pounds per square foot with an eight foot girt spacing (Manta, 1976:5). The girts would be standard steel channels and span the 20 foot distance between exterior columns. A system of tie rods would be added to provide weak axis support for the girts. Figure 11 shows the girt and tie rod arrangement.

Cost Consideration and Results. This section will present the cost considerations and the cost results for the exterior wall. The initial cost of the wall was calculated and converted to an annual cost using a 25 year life and an interest rate of 10 percent. It was assumed that the wall would require no maintenance; therefore, no maintenance cost was added to the annual cost. It was also assumed that the wall would have zero salvage value after the 25 year life.

The cost of the tilt slab portion includes the installed cost of the tilt slab including the sealant between slabs, the insulation and the inner lining. The upper portion or steel sandwich portion cost includes the installed cost of the steel sandwich panels, insulation and inner liner, plus the cost of the steel for the girts and tie rods. The cost of doors was not included. The cost results for each building are presented in Tables 9, 10 , 11, and 12.

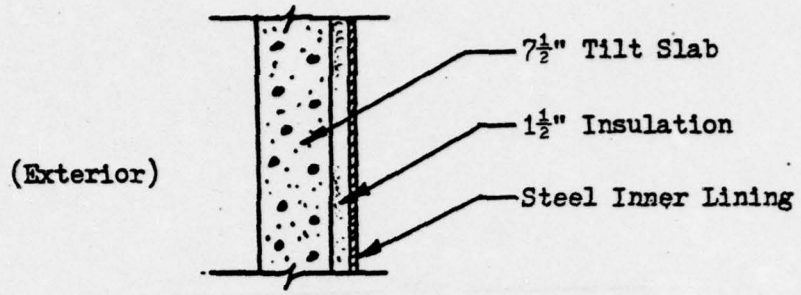


FIGURE 9 CROSS SECTION OF THE TILT SLAB PORTION OF THE EXTERIOR WALL

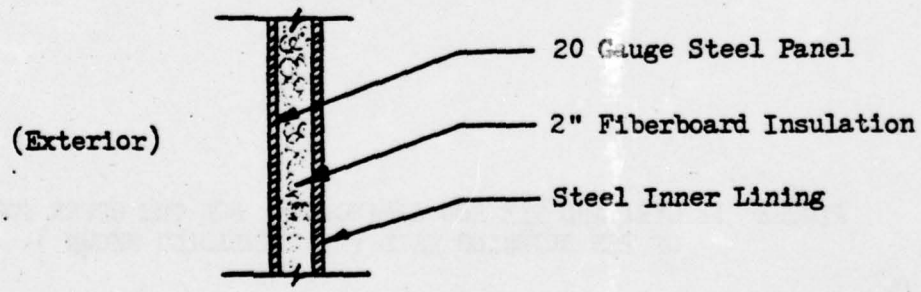


FIGURE 10 CROSS SECTION OF THE STEEL SANDWICH PANEL PORTION OF THE EXTERIOR WALL

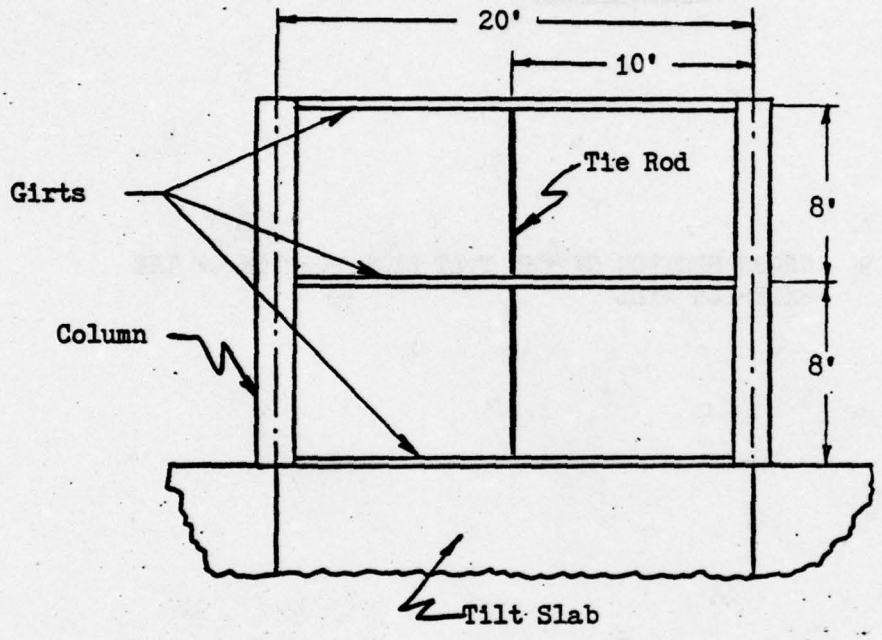


FIGURE 11 GIRT AND TIE ROD ARRANGEMENT FOR THE UPPER PORTION OF THE EXTERIOR WALL (30' BUILDING SHOWN)

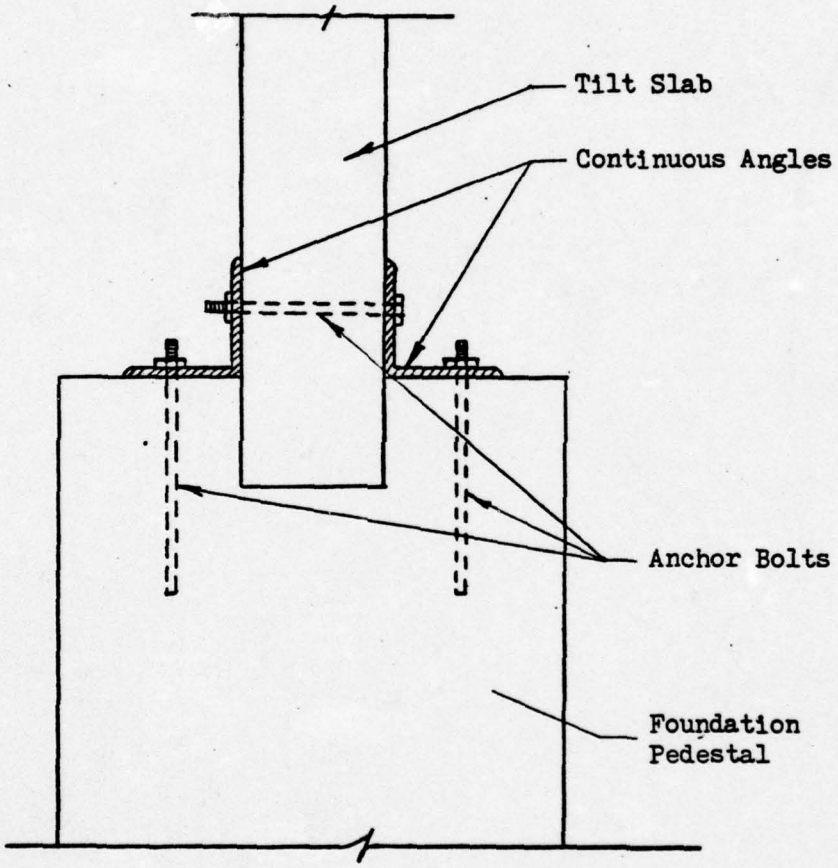


FIGURE 12 DETAIL OF TILT SLAB AND FOUNDATION CONNECTION

TABLE 9

EXTERIOR WALL COSTS FOR 30 FOOT BUILDING

ITEM	OPER AREA	MECH AREA	GENERAL STORAGE AREA	TOTAL
Exterior Wall Area For Tilt Slab	66,000	13,200	72,400	-------
Cost Per Sq Ft Of Tilt Slab *	3.68	3.68	3.68	-------
Exterior Wall Area For Sandwich Panel	52,800	10,560	57,920	-------
Cost Per Sq Ft Of Sandwich Panel **	3.62	3.62	3.62	-------
Total Initial Cost	434,016	86,803	476,102	996,921
Total Annual Cost	47,816	9,563	52,452	109,831
Cost Per 1000 Cu Ft	-------	------	-------	1.60

* (Means, 1975:111,276)

** (Means, 1975:116)

TABLE 10

EXTERIOR WALL COSTS FOR 40 FOOT BUILDING

ITEM	OPER AREA	MECH AREA	GENERAL STORAGE AREA	TOTAL
Exterior Wall Area For Tilt Slab	66,000	13,200	72,400	-------
Cost Per Sq Ft Of Tilt Slab *	3.68	3.68	3.68	-------
Exterior Wall Area For Sandwich Panel	52,800	17,160	90,920	-------
Cost Per Sq Ft Of Sandwich Panel **	3.62	3.62	3.62	-------
Total Initial Cost	434,016	110,695	595,562	1,140,273
Total Annual Cost	47,816	12,195	65,613	125,624
Cost Per 1000 Cu Ft	-------	-------	-------	1.46

* (Means, 1975:111,276)

** (Means, 1975:116)

TABLE 11

EXTERIOR WALL COSTS FOR 50 FOOT BUILDING

ITEM	OPER AREA	MECH AREA	GENERAL STORAGE AREA	TOTAL
Exterior Wall Area For Tilt Slab	66,000	13,200	72,400	-------
Cost Per Sq Ft Of Tilt Slab *	3.68	3.68	3.68	-------
Exterior Wall Area For Sandwich Panel	52,800	23,760	123,920	-------
Cost Per Sq Ft Of Sandwich Panel **	3.62	3.62	3.62	-------
Total Initial Cost	434,016	134,587	715,022	1,283,625
Total Annual Cost	47,816	14,827	78,774	141,417
Cost Per 1000 Cu Ft	-------	-------	-------	1.37

* (Means, 1975:111,276)

** (Means, 1975:116)

TABLE 12

EXTERIOR WALL COSTS FOR 60 FOOT BUILDING

ITEM	OPER AREA	MECH AREA	GENERAL STORAGE AREA	TOTAL
Exterior Wall Area For Tilt Slab	66,000	13,200	72,400	-------
Cost Per Sq Ft Of Tilt Slab *	3.68	3.68	3.68	-------
Exterior Wall Area For Sandwich Panel	52,800	30,360	156,920	-------
Cost Per Sq Ft Of Sandwich Panel **	3.62	3.62	3.62	-------
Total Initial Cost	434,016	158,479	834,482	1,426,977
Total Annual Cost	47,816	17,460	91,935	157,210
Cost Per 1000 Cu Ft	-------	-------	-------	1.30

* (Means, 1975:111,276)

** (Means, 1975:116)

Roofing

The roofing for the warehouse module has to provide sufficient insulation for reducing heating and cooling costs, as well as provide protection from the weather. Insulating properties of the roof were investigated with the ECUBE computer program. A U value of .075 was determined to be optimum for the warehouse. Refer to the "HVAC Energy Requirements" section for detailed information on this selection. An important qualification in weather protection is adequate drainage. A slope of 0.25 inches per foot was provided to eliminate standing water on the roof (AFM 88-15, 1975:3-24). Interior drains were selected to carry off any rainfall. Weight, insulating qualities, fire resistant qualities, and economics all entered into the decision for the selection of roofing. A 20 gauge steel deck supporting the insulation and four-ply membrane roofing was the final selection.

Deck. The deck had to be capable of supporting a dead load of its own weight plus the weight of insulation, membrane, and protective covering. Support was also provided for a live snow load of 20 pounds per square foot. A 20 gauge steel deck was selected.

A steel deck was lighter than concrete or gypsum, and a savings was realized in other costs (Appendix C-4). The weight of the roof with a steel deck was nine to ten pounds per square foot depending on insulation. Roofs with concrete decks weighed 18 pounds per square foot and heavier (Carrier, 1972:1-71). While 22 gauge steel has adequate strength to support the required loads, it is recommended that 20 gauge decking be utilized (Construction, 1970:38). The 22 gauge deck tends to suffer damage due to handling in shipping and construction. The damage results in gaps

in the seals between strips of the deck (Construction, 1970:31).

Insulation. Insulation was added to the roofing to reduce energy consumption in heating and cooling. The roof was the primary surface area for building heat loss or gain with respect to outside weather conditions. The insulation selected for the warehouse was a fifteen-sixteenth of an inch layer of rigid fiber glass placed on the deck, followed by 1.25 inches of urethane on the fiber glass (Appendix C-4).

Covering and Protection. It was assumed that the warehouse would be located a sufficient distance from aircraft warm-up and operating aprons. Some of the aggregate could get on the surrounding ground surface due to weather erosion. If it gets onto the surfaces on which jet aircraft operate, the aggregate could be injested in the engine, causing expensive engine repair or replacement. This eliminated the requirement for a more expensive smooth surface roofing (AFM 88-15, 1975:3-24). An aggregate covering was used as a protective covering for the membrane layer.

A four-ply, built-up roof with asphalt saturated organic felt topped with type I asphalt, topped with a suitable aggregate was selected for the warehouse (AFM 88-15, 1975:3-23). A light colored aggregate was chosen for economical operation of the environmental controls inside the warehouse.

Costs. The initial construction cost for the roof is $2.40 per square foot. This converts to the cost per 1000 cubic feet as depicted in Table 13.

TABLE 13

ROOFING COSTS

Clear Height (Ft)	30	40	50	60
Cost ($ Per 1000 Cubic Feet)	80.00	63.78	53.03	45.38

Due to the variables involved, the cost estimates in Table 13 were made assuming a life of 25 years. There are many different kinds of built-up roofs. There are many different manufacturers of the felts, tars, and asphalts used in the construction of the roof. It is very important that the proper supplies are furnished by the roofing contractor. It is also important that he follow established procedures in the construction of the roof. GCE-76S recommends that an inspector, knowledgeable in roofing procedures, be on duty full time to check on the condition of the materials used, and on the construction process. It is all too possible to have failure of the roof in as short a time as five years. It is also possible to have a roof life in excess of 20 years. The difference between the two can be contributed to the materials used or the construction process, or both.

Rain Runoff. The Rational Method was used for estimating the amount of rain runoff. The formula for the Rational Method was:

$$Q = CIA \quad \text{(AFP 88-27, 1973:7-1)} \qquad (3)$$

where:

Q = The peak rate of runoff in cubic feet per second

C = A runoff coefficient

I = The average rainfall intensity in inches per hour

A = The drainage area in acres

It was assumed that the rainfall intensity was uniform over the roof area.

The runoff coefficient accounts for infiltration and detention, and a value of 0.95 was used for a watertight roof (AFP 88-27, 1973:7-3). Average rainfall intensity for a 30 minute rainfall recurring every two

years was 2.8 inches per hour. Values of 3.64 inches per hour and 4.48 inches per hour were used for 30 minute rainfalls with recurrences of five and ten years respectively (AFP 88-27, 1973:7-2). A value of 52 acres was used for the roof area. Three values of rain runoff were calculated and the duration remained at 30 minutes. The rate of runoff, in cubic feet per second, was 138.3 for a two year interval, 179.8 for a five year interval, and 221.3 for a ten year interval. These were the peak flow rates that enter into the building drainage system. The drainage area for one roof drain was 0.33 acres and the resultant volume flow rates for one roof drain were 0.88, 1.14, and 1.4 cubic feet per second for the three recurrence intervals.

Foundations and Floor

Foundations were required for the building shell, interior and exterior walls, and the bridge crane system. Conventional reinforced concrete footings were analyzed for the various foundation requirements encountered. However in some cases, because of the nature of the soil in the Norfolk area, pile foundations were found to be structurally necessary and/or more economical. The building floor was designed to meet anticipated intensity and frequency of traffic loads, and to provide for uniform live loads of 1,000 to 8,000 psf. In order to demonstrate the cost effectiveness of improved soil conditions, a summary of floor cost versus soil bearing capacity for the required loading range was produced. The foundation types are as follows:

1. Interior column foundation - gravity loads only.
2. Transition column foundation - gravity loads and bending moment about one axis due to wind.
3. Corner column foundations - gravity loads and bending moment about two axes due to wind.
4. Interior wall foundations - continuous wall load and overturning moment.
5. Exterior wall foundations - continuous wall load and exterior column loads with applied wind moment.
6. Crane column foundations - combined crane column and building column gravity loads and wind moment.

Soil Properties. The absence of adequate site information and the basis of selection of a 1,000 psf allowable soil bearing capacity was discussed in the "Design Parameter" section. Other soil parameters

used in the design included a defined frost line of ten inches and an assumed water table at approximately nine feet (AFM 88-3, 1966:15). Soil density was estimated to be 110 psf (Naval Supply Center, 1973:12). For the floor design, a summary of modulus of subgrade reaction values for typical soils is included in Table 15.

Pile Foundations. The design of pile foundations is entirely site dependent and could not be undertaken completely within the scope of this study. Accurate subsoil information is required in order to effectively design a pile foundation, and as previously discussed this data was not available. However, in order to assess the feasibility and economy of the foundation systems designed, some estimates of achievable pile capacities and costs were considered consistent with current pile foundation applications within the Norfolk area.

TABLE 14

PILE DATA *

PILE TYPE	DIAMETER	CAPACITY	ASSUMED LENGTH	COST
Precast Concrete	10 In	50 Tons	50 Ft	$4.50/Ft
Timber	12-20 In	30 Tons	50 Ft	$3.50-3.80/Ft

* (McAndrews, 1976)

Foundation Design. A number of foundation types were examined and those with direct application were strip footings, square and rectangular spread footings, and pile foundations. Raft footings were considered,

TABLE 15

A SELECTION OF TYPICAL SOIL PROPERTIES

SOIL TYPE*		BEARING CAPACITY (PSF)+	MODULUS OF SUBGRADE REACTION (PCI)+
GW	Gravel Or Sandy Gravel Well Graded	8,000	500
GP	Gravel Or Sandy Gravel Poorly Graded	6,000	400
GM	Silty Gravel Or Silty Sandy Gravel	4,000	300
SM	Silty Sand Or Silty Gravelly Sand	3,000	300
ML	Silts, Sandy Silts Gravelly Silts	2,000	200
CL	Lean Clays, Sandy Clays	1,000	150

* Unified Soil Classification

+ Typical values for soil types (Singh, 1967:184)

but as the total required footing area did not exeed half the plan area in cases investigated, these were not used.

A significant amount of preliminary investigation was undertaken with the aim of reducing the possibility of differential settlements within the facility. The method of proportioning footings by assuming probable live load ratios was pursued in some detail (Spangler, 1960 :356). However, because of the lack of knowledge of soil properties and the probable variation within the 50 acre area selected, further detailed settlement analysis was considered unwarranted. As a guide to minimizing settlement, local design practice in the Norfolk area is to limit footing dimensions to 15 feet. This restricts the penetration of significant pressures into the soil to about 15 feet. Apparently, below the reasonably firm surface crust, unconsolidated strata are frequently encountered at about the 15 foot level.

Type 1 footings required design for gravity loads only. Since the roof frame was the heaviest part of the structure, the contribution of column weight to the total foundation load was minimal. As a result the variation of foundation load for structure heights from 30 feet to 60 feet was in the range of 135 to 140 kips. A single column footing design was considered satisfactory for the full range of building heights where only gravity loads were involved. For the special case of the operating area where 60 feet by 36 feet bays were designed, and additional column loads included provision for conveyor systems, the foundation load was 126 kips. Footing design was based upon selecting an adequate square footing area compatible with soil bearing capacity and then designing the thickness to meet shear and bending stresses. Sample calculations

for type 1 footings are shown at Appendix C-5 and a summary of footing dimensions is included in Table 16.

Footing types 2 and 3 were designed to meet applied wind moments in addition to the gravity loads used in type 1 footings. Therefore, the minimum area of these footings was the same as for type 1 footings. In designing footings for moment, one method employed is to calculate an equivalent eccentricity of load that would produce the same moment condition. Recommended practice is to limit the resultant eccentricity to within the middle one-third of the footing (Bowles, 1968 : 213). The footings were designed to withstand the largest moment condition from the STRESS output for each of the 30 foot, 40 foot, 50 foot, and 60 foot buildings. Footing dimensions varied from 21 feet for the 60 foot high building to 15 feet for the 30 foot high building. As a spread footing design of less than 15 feet was desirable in the poor soil conditions assumed, an analysis of pile foundations was undertaken.

Pile supported footings not only proved adequate but also were more economical than the large spread footings. Because the final location of any pile may be three inches or more from its desired location it is not good practice to use fewer than three piles for the support of a column unless lateral structural framing capable of withstanding the bending moments due to the possible eccentricity is provided (Gaylord, 1968:5-73). For transition column foundations, three piles per footing were used. For corner columns, where moment resistance was required in two directions, a four pile foundation was used. Typical pile foundation plans are shown in Figure 13 and 14. A minimum pile spacing of five pile diameters was assumed in order to eliminate the possible loss of pile capacity due to

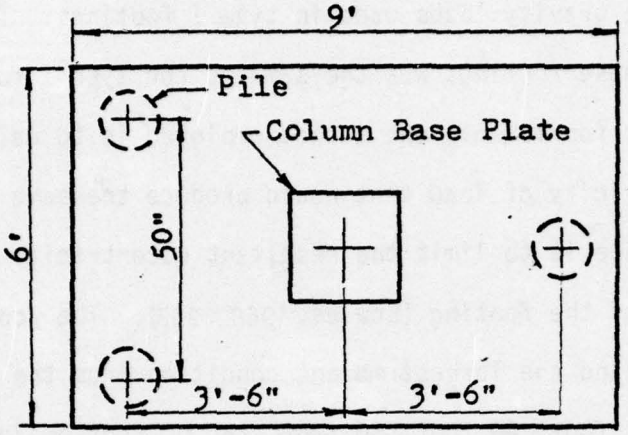


FIGURE 13 TRANSITION COLUMN FOUNDATION 60 FOOT BUILDING

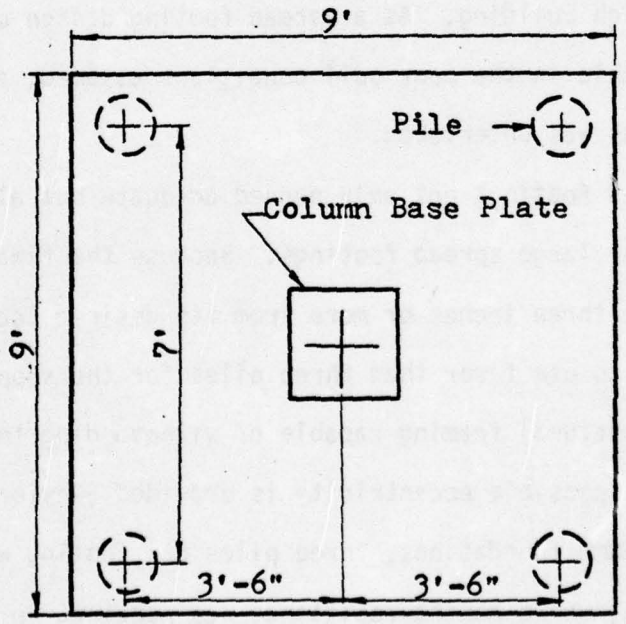


FIGURE 14 CORNER COLUMN FOUNDATION 60 FOOT BUILDING

group action (Spangler, 1960:386). Typical calculations for both spread footings and pile foundations for footing types 2 and 3 are shown in Appendix C-6. A summary of footing dimension is included in Table 16.

A discussion of the type 4 interior wall footings is included in the "Interior Walls" section. It was decided to cost the entire interior wall component separately because of the unknown extent of this facet.

The exterior wall, or type 5 footing, was designed as a continuous spread footing connected to the tilt slab portion of the perimeter wall. The tilt slab wall was designed so that it would take a portion of the wind load. It was necessary to design the footing to withstand this wind load. Figures 15 and 16 show the design models used to develop the size of footing required. Appendix C-7 contains a detailed design development and cost analysis. The results are presented in Table 16.

Footing type 6 for the bridge crane structure was designed to support the crane frame columns and the train shed columns. The two loading cases investigated are shown in Figures 17 and 18. Appendix C-8 contains a detailed development and cost analysis. The design and cost results are presented in Table 16.

Floor Design. Small floor areas may be designed as simple slabs when loads are in excess of the allowable soil capacity (e.g. by improving the subgrade). Generally however, the limiting case for a slab on grade is where the total floor load including slab weight is equal to the soil bearing capacity. The assumed soil bearing capacity of 1000 pounds per square foot for the Norfolk area presented some difficulty in achieving the desired floor loading range of 1000 to 8000 pounds per square foot. A floor load of 1000 pounds per square foot was assumed to be achievable

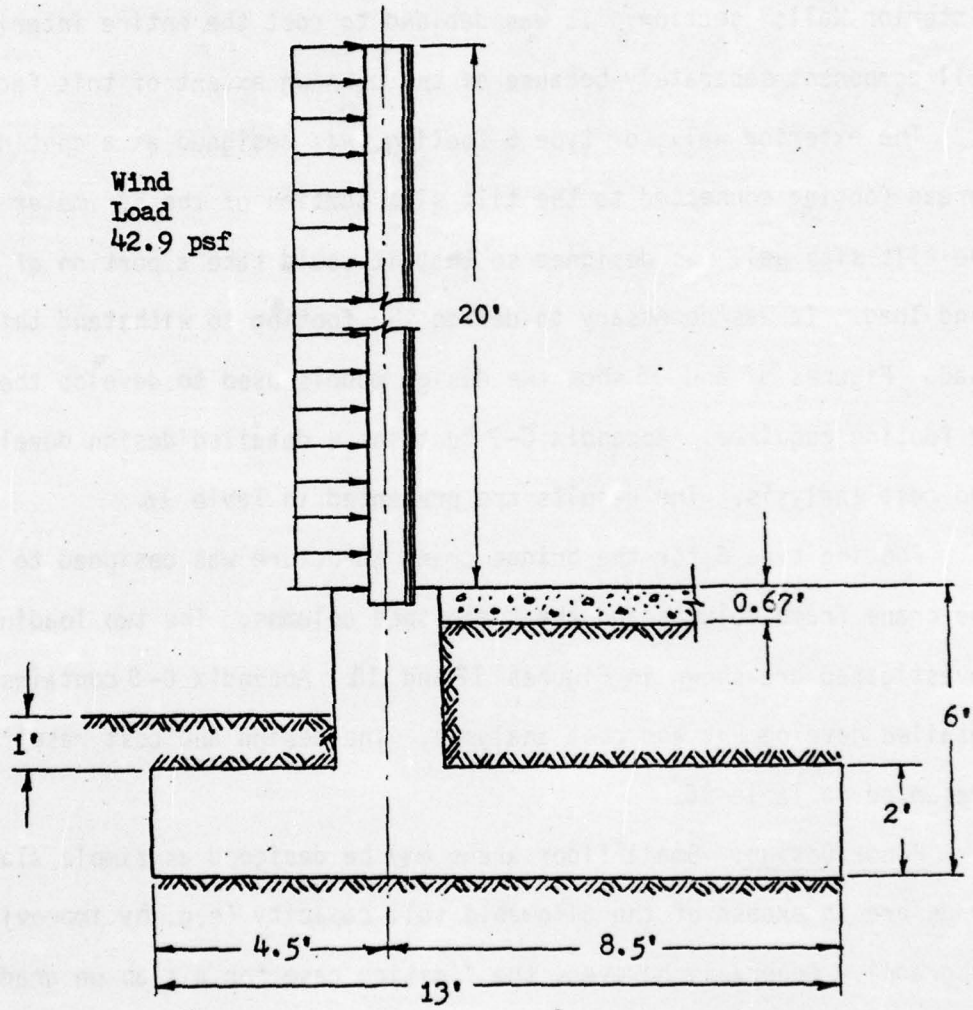


FIGURE 15 EXTERIOR WALL FOOTING MODEL, CASE 1

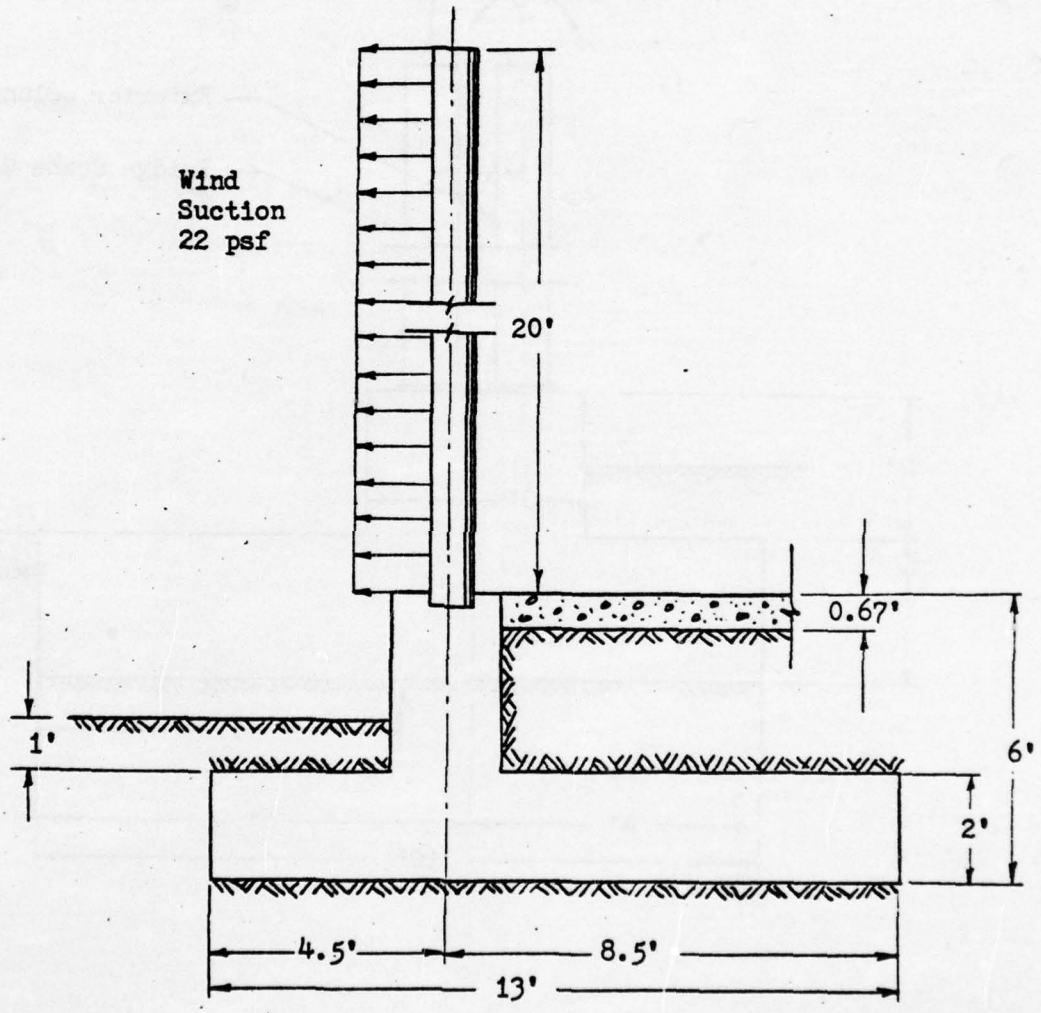


FIGURE 16 EXTERIOR WALL FOOTING MODEL, CASE 2

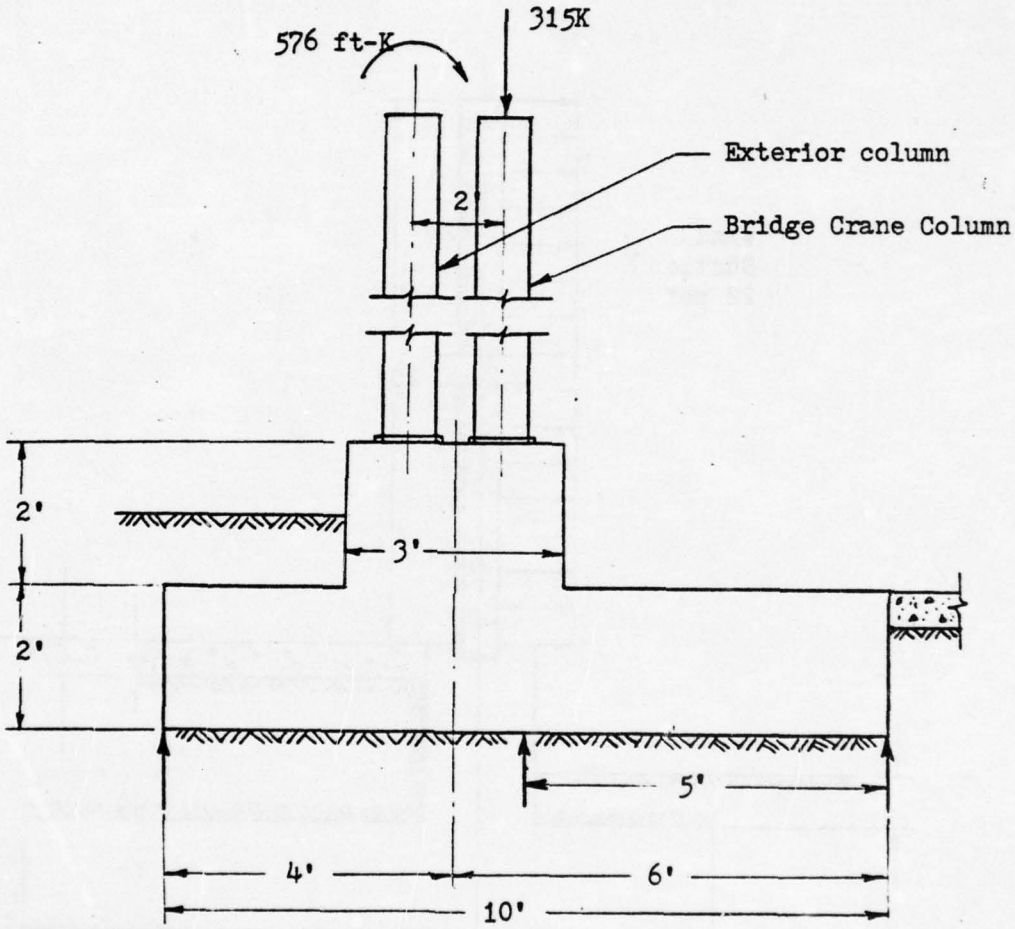
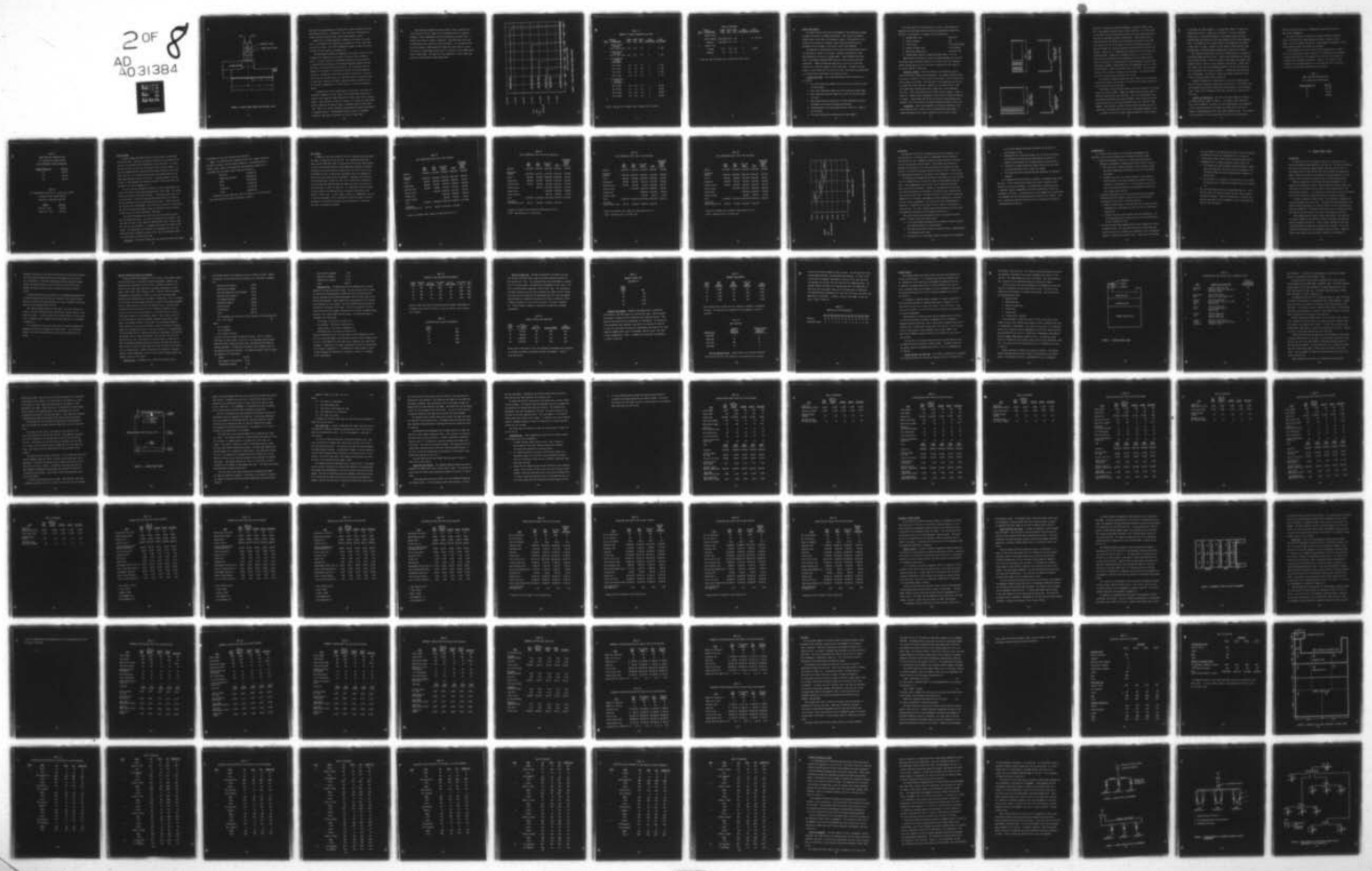


FIGURE 17 BRIDGE CRANE FOOTING DESIGN MODEL, CASE 1

AD-A031 384 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 13/2
A GENERAL WAREHOUSE MODULE CONCEPTUAL DESIGN AND COST ANALYSIS.--ETC(U)
SEP 76 R T ALEXANDER, T J CARMICHAEL

UNCLASSIFIED GCE/MC/76S-1-VOL-2 NL

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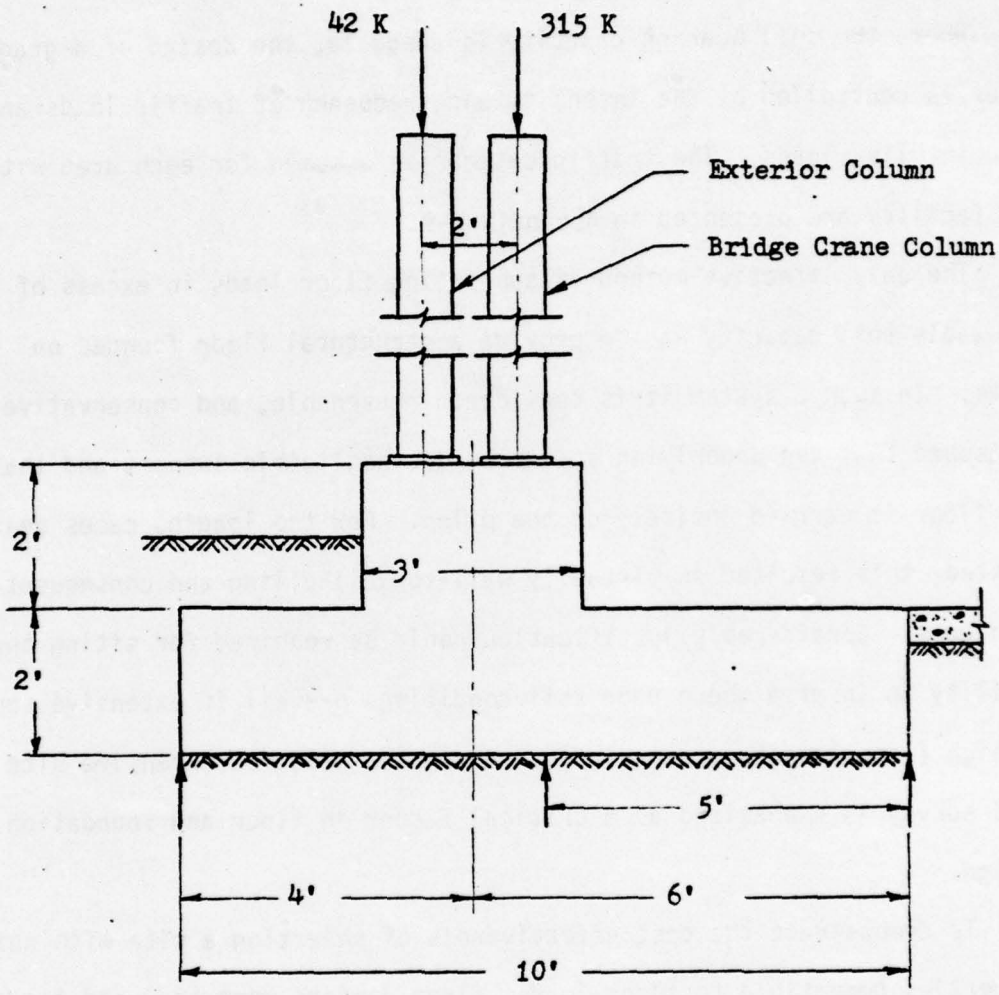


FIGURE 18 BRIDGE CRANE FOOTING DESIGN MODEL, CASE 2

with slab on grade construction although this slightly exceeded the allowable bearing capacity. An additional floor load case of 500 pounds per square foot was included to meet a more recent request by EATG.

Where the soil bearing capacity is adequate, the design of a grade floor is controlled by the intensity and frequency of traffic loads and/or point live loads. The traffic categories assumed for each area within the facility are presented in Appendix C-9.

The only effective method of supporting floor loads in excess of the allowable soil capacity was to provide a structural floor founded on piles. In such a system it is considered reasonable, and conservative, to assume that the underlying soil provides negligible support and that the floor is carried entirely on the piles. For the loading cases requested, this resulted in virtually wall-to-wall piling and consequent high cost. Considerable justification would be required for siting the facility in an area where poor soil conditions prevail if extensive zones of high floor loading are included. Again the need for extensive site soil survey is emphasized as a critical factor in floor and foundation design.

To demonstrate the cost effectiveness of selecting a site with soil properties compatible to floor loads, floor designs were analyzed for a range of soil properties rather than for the single values used in footing design. Table 15 shows a selection of typical soil types with approximate bearing capacities and typical moduli of subgrade reaction (Singh, 1967 : 70). There is no direct correlation between bearing capacity and modulus of subgrade reaction. The tabulated values are merely a reasonable estimate of some typical properties for the soil types shown.

Using these soil properties and the traffic loads, a tabulation of floor costs for the full range of floor loadings versus soil type was produced. Floors supported on piles were designed as two-way slabs. A graph of the results is shown in Figure 19. The graph shows floor cost per 1000 square feet versus soil bearing capacity. As an example of the use of this graph, a 3000 pounds per square foot floor load on a sound soil such as a sandy gravel would result in a capital cost per 1000 square feet of about $1260. The same floor load supported on a poor sandy clay would cost about $9,140 per 1000 square feet.

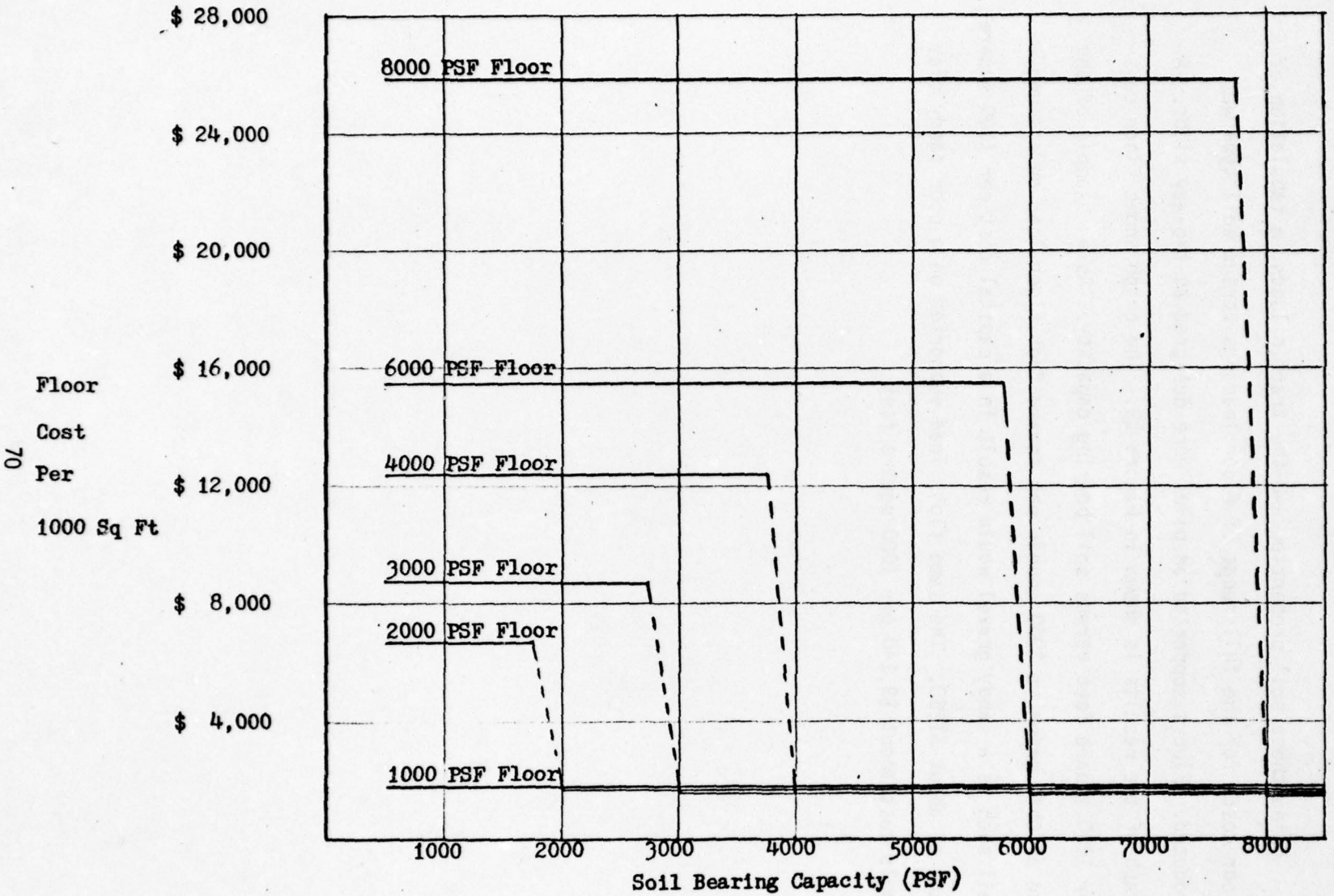


FIGURE 19 FLOOR COST VERSUS SOIL BEARING CAPACITY

TABLE 16

SUMMARY OF FOOTING DIMENSIONS AND COSTS

TYPE	FOOTING DESCRIPTION	LENGTH (FT)	WIDTH (FT)	DEPTH (FT)	PILES PER FOOTING	COST PER FOOTING
1	Square Spread Footing 60 Ft X 60 Ft Bay	12.0	12.0	1.0	---	$ 384
1	Square Spread Footing 60 Ft X 36 Ft Bay	11.5	11.5	1.0	---	$ 353
2	Pile Supported Footing 1-Way Moment					
	60 Ft Bldg	9.0	6.0	2.0	3	$ 963
	50 Ft Bldg	7.5	5.0	2.0	3	$ 875
	40 Ft Bldg	6.0	4.0	2.0	3	$ 803
	30 Ft Bldg	5.0	4.0	2.0	3	$ 782
3	Pile Supported Footing 2- Way Moment					
	60 Ft Bldg	9.0	9.0	2.0	4	$1,332
	50 Ft Bldg	7.5	7.5	2.0	4	$1,200
	40 Ft Bldg	6.0	6.0	2.0	4	$1,092
	30 Ft Bldg	5.0	5.0	2.0	4	$1,033
4*						

* Type 4 footings are included in the "Internal Walls" section.

TABLE 16 CONTINUED

TYPE	FOOTING DESCRIPTION	LENGTH (FT)	WIDTH (FT)	DEPTH (FT)	PILES PER FOOTING	COST PER FOOTING
5	External Wall					
	Strip Footing	Continuous	13.0	2.0	---	$ 90.72 **
	Pedestal	Continuous	2.0	4.0	---	
6	Bridge Crane					
	Footing	12.0	8.0	2.0	5	$1,684
	Pedestal	3.0	3.0	2.0	---	

** Cost for type 5 footings are in dollars per linear foot

Bridge Crane System

An integral part of the overall development of the warehousing concept included the design of a bridge crane system. This system incorporates bridge cranes, crane frame, and foundation support. The objective of this portion of the study was to design a crane system and develop costing information to be included in the overall cost of the warehouse.

The approach to the problem initially dealt with establishing criteria for the physical layout of the system. Secondly, representative loads were developed to be used in a design model. These parameters were then used in the computer program STRESS which was used to analyze the crane frame model. STRESS provided the capability to arrive at an efficient design of the individual members of the crane frame. Although the crane system is interrelated with the overall facility, the design was accomplished so it would not be restricted to one particular area.

Criteria and Loads. The criteria developed by EATG and GCE-76S are as follows:

1. Two crane systems were needed, one each on the east and west sides of the building.
2. Each crane frame would support two 60 ton capacity bridge cranes.
3. Each system must have the capability to spot ten 88 foot flatbed rail cars.
4. Each system would be enclosed by a building compatible with and contiguous to the overall warehousing structure.
5. Column spacing of the crane frame would be limited to a range of 20 to 30 feet.
6. The crane frame would be constructed of steel members.

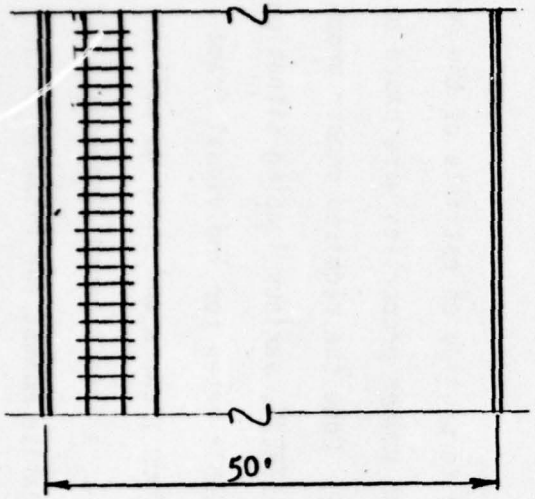
The loads used for the actual analysis as well as the dimensional properties of the bridge crane were taken from manufacturers data (Otis, 1975:23). The following is a summary of this information:

1.	Maximum wheel load	46.65 kips
2.	Impact allowance	15%
3.	Lateral load	5% of gross weight
4.	Spacing of wheel loads	5 foot centers
5.	Wheels per bridge crane	4 on each side
6.	Minimum wheel spacing of adjoining bridge cranes	6 ft 2 in

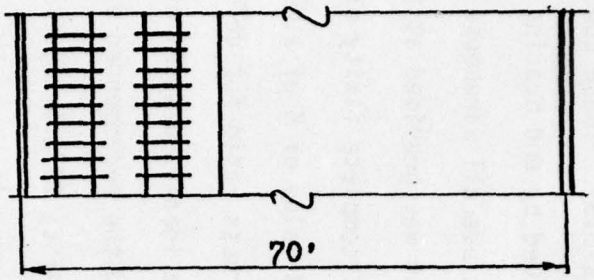
Specifications pertaining to vertical clearance between rail cars and the bridge crane, horizontal spacing of rail track lines, and clearances between loading docks and rail lines were incorporated in the layout of the system (AFM 88-7, 1971:2-14).

Functional Schemes. Within the bounds of the preceding criteria, several functional schemes were investigated. One scheme involved an analysis using a single rail line to spot ten cars versus a dual line with five cars on each set of tracks. The trade off in this comparison was the cost of an 880 foot crane frame and a single rail line versus that of a 440 foot crane frame, abridge crane with a larger span, and an additional rail line. A plan and elevation view of each of these layouts is shown in Figure 20. Another factor considered in the functional scheme was spacing of columns. Crane frames with 20, 25, and 30 foot column spacings were analyzed. The final selection of column spacings was based on least cost.

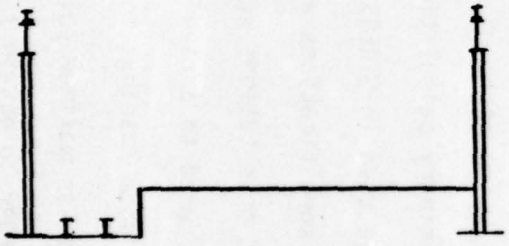
Assumptions. One of the assumptions in the actual modeling of the crane frame was that it would act an an indeterminant braced frame. A braced frame whose joints cannot translate is one in which "lateral



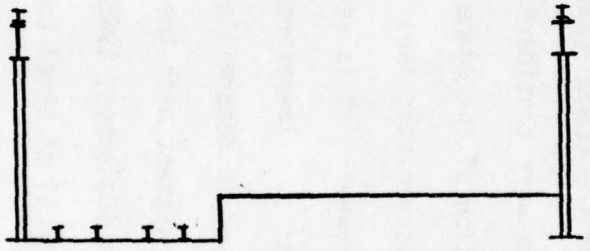
Plan View
Single Track



Plan View
Dual Track



Elevation View
Single Track



Elevation View
Dual Track

FIGURE 20 ILLUSTRATION OF ALTERNATE LAYOUTS

stability is provided by adequate attachment to diagonal bracing, shear walls, and adjacent structure having lateral stability, or to floor slabs or roof decks secured horizontally by walls or bracing systems parallel to the plane of the frame" (Salmon, 1971:812-813). These conditions for a braced frame were considered to be provided by end bracing of the frame and connection of the crane frame to the overall warehouse structure. It was also assumed that ideal end restraint was provided at the base of all columns. However, it is recognized that complete fixity of the base cannot be attained. Therefore an increased value of K of 1.0 in lieu of 0.65 was used in determining the slenderness ratio for column analysis. This is consistent with the conservative idealized model of braced frames by Galambos (Galambos, 1968:176-189) and the recommended value of KL from the AISC Manual of Steel Construction (AISC, 1973:5-25). The beam across the top of the columns was assumed to be continuous. The joints formed by these connections were considered to be rigid.

An assumption regarding bridge crane wheel loads was that they would act as point loads on the beam when in reality they are point loads on the crane rail which rests on the beam.

Preliminary calculations were made to provide an estimate of the member sizes to be used in STRESS. Members and member properties were based on 1973 AISC specifications and A-36 steel. Once the required member properties and orientations were placed in STRESS, various loading situations were considered to arrive at worst possible cases for individual frame members. Beam loadings to produce maximum flexure and shear as well as conditions for maximum column stresses were investigated (Appendix C-11).

In order to obtain the largest negative moment for flexural design

of the beams, the spans adjacent to a column were loaded. To obtain the largest shear value in a beam, the first wheel of a set was positioned directly over a column and the wheels of the second bridge crane were centered about the centerline of the span adjacent to that column (Appendix C-11). The beams were also loaded to obtain the maximum positive moment at the center of a span. However, for the range of column spacings under consideration, the maximum negative moment case controlled the design.

The loading situation most critical for column design is a function of the bending moment and axial force. Column forces resulting from loadings that produced the most critical situations in the beams were checked using combined stress criteria to assure adequate column design. Columns with the largest axial load and accompanying moment as well as the largest moment and related axial load were analyzed. Intermediate conditions were also investigated. The analysis of beams and columns were based on AISC criteria and design theory (AISC, 1973:5-22).

Foundation support was a consideration in the crane framing system. Due to low bearing capacities associated with the soils in the Norfolk area, pile foundations and spread footings were each analyzed to carry structure loads. Refer to the "Foundations and Floor" section for a discussion of this topic.

Results and Conclusions. The cost of the crane frame as a function of column spacing is shown in Table 17. The figures shown include the cost of the foundation. By using a 30 foot column spacing, the foundation of the structure enclosing the bridge crane system can be utilized to handle a large percentage of the crane frame foundation loads. This accounts for the similarity in cost between the 20 and 30 foot column spacings.

Table 18 illustrates the cost if independent foundations are used for each column arrangement.

The results (Table 17) indicate the combined frame and foundation costs of 20 and 30 foot column spacings are within 2 percent of each other. Due to the greater flexibility in moving material through the larger column spacing, the 30 foot spacing was selected.

A cost comparison of a dual line rail track system versus a single line rail track system is shown in Table 19. An additional cost advantage is realized with the dual line system in that the size of the enclosing structure can be reduced by 30 percent. However, this savings is not included in the aforementioned data. By selecting the dual line system, a savings of approximately $50,000 would be achieved.

TABLE 17

CRANE FRAME AND FOUNDATION COST

AS A FUNCTION OF COLUMN SPACING

COLUMN SPACING (FT)	COST ($)
20	107,357
25	125,707
30	108,550

TABLE 18

CRANE FRAME AND FOUNDATION COST

AS A FUNCTION OF COLUMN SPACING

USING INDEPENDENT COLUMN FOUNDATIONS

COLUMN SPACING (FT)	COST ($)
20	128,717
25	136,387
30	151,270

TABLE 19

COST COMPARISON OF DUAL RAIL VS. SINGLE RAIL SYSTEMS

UTILIZING 30 FOOT COLUMN SPACING,

EXCLUSIVE OF ENCLOSING STRUCTURE

SYSTEM	COST ($)
Dual Rail Track	636,649
Single Rail Track	685,048

Secure Storage

A square storage vault 180 by 180 by 34 feet high was incorporated into the facility. There was no specific criteria on the location of the vault so it was placed at the intersection of two fire walls. By using the two fire walls as vault walls the overall cost could be reduced. It was also assumed that the roofing would be placed directly on top of the vault roof slab. No consideration was given to placing offices of any other type structure on top of the vault. To meet the general fire wall criteria in the warehouse the remaining two walls of the vault were also designed as fire walls (Appendix C-3).

The vault roof was designed as an eight inch thick light-weight concrete slab placed on steel decking supported by a steel frame. The column spacing was reduced to 30 feet by 30 feet. A two-way concrete roof slab was investigated. The cost of erecting forms and shores at a height of 35 feet exceeded the cost of steel decking and joists. Precast concrete roof sections were investigated. The sections are cellular in construction and did not provide the minimum 8 inches of reinforced concrete required to meet the vault criteria (AFM 88-15, 1975:3-59).

The vault incorporated the existing 30 foot high lighting system and fire protection system. The vault was designed with two doors. The main door will have to be a specially designed vault door so that a small fork lift can pass through it. A standard vault door is 40 inches by 78 inches. The second door was installed as an emergency exit only. By placing the doors at opposite corners of the vault the maximum distance to an exit would be less than 200 feet.

Conclusion. The secure storage vault was designed to meet the storage

requirements of up to and including secret material.

Cost. The vault cost only includes the roof slab, support structure, two walls, two doors, and the column foundation. The remaining cost of roofing, floor, lights, fire protection, and mechanical systems are incorporated into the overall cost of the entire facilty.

Roof slab	$ 48,563.00
Supporting structure	$164,821.00
Walls	$ 60,005.00
Doors	$ 15,205.00
Foundations	$ 19,757.00
Total	$208,351.00

Additional cost per 1000 cubic feet to construct a 1.1 million cubic foot vault based on the above limitations is $279.91.

Cost Summary

A summary of the costs related to the civil engineering design aspects are shown in Tables 20, 21, 22, and 23. This information shows that a least cost per 1000 cubic feet is achieved with the 60 foot high building. It should be noted that materials and systems were selected to minimize maintenance costs which could be incurred over the life of the facility. By allowing for this in the design, maintenance costs for components of the facility were either zero or negligible. Therefore, the equivalent uniform annual costs include only the initial construction expenditures. A curve showing the combined costs per 1000 cubic feet as a function of building height is shown in Figure 21. It is emphasized that the design and cost analysis was based entirely on conditions pertaining to the Norfolk, Virginia area. In this regard, caution is recommended in the use of the data developed. While interpolation within the range of defined parameters is considered reasonable, any extrapolation of the results may lead to erroneous conclusions.

TABLE 20

CIVIL ENGINEERING COSTS FOR 30 FOOT BUILDING

	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL	EQUIVALENT UNIFORM ANNUAL COST
Roofing	1,114,560	1,045,440	3,320,640	5,480,640	603,802
Structural Framing	1,485,728	1,154,588	3,322,032	5,962,348	656,872
Floor *	650,160	609,840	1,646,568	2,906,568	320,217
Foundations	466,490	138,611	603,872	1,208,973	133,193
Exterior Walls	434,016	86,803	476,102	996,921	109,831
Interior Walls		610,700	2,808,672	3,419,372	376,712
Bridge Crane			1,258,898	1,258,898	138,693
Secure Storage			308,351	308,351	33,971
Total	4,150,954	3,645,982	13,745,135	21,542,071	2,373,290
Equivalent Uniform Annual Cost	457,311	401,678	1,514,302	2,373,290	

* Based on allowable floor loading of 1000 pounds per sq ft

TABLE 21

CIVIL ENGINEERING COSTS FOR 40 FOOT BUILDING +

	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL	EQUIVALENT UNIFORM ANNUAL COST
Roofing	1,114,560	1,045,440	3,320,640	5,480,640	603,802
Structural Framing	1,485,728	1,374,727	3,752,574	6,613,029	728,557
Floor *	650,160	609,840	1,646,568	2,906,568	320,217
Foundations	466,490	178,582	609,036	1,254,108	138,165
Exterior Walls	434,016	110,695	595,562	1,140,273	125,624
Interior Walls		863,710	3,972,290	4,836,000	532,782
Bridge Crane			1,258,898	1,258,898	138,693
Secure Storage			308,351	308,351	33,971
Total	4,150,954	4,182,994	15,463,919	23,797,867	2,621,811
Equivalent Uniform Annual Cost	457,311	460,840	1,703,660	2,621,811	

* Based on allowable floor loading of 1000 pounds per sq ft

+ Note: Operating area is 30 feet high

TABLE 22

CIVIL ENGINEERING COSTS FOR 50 FOOT BUILDING +

	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL	EQUIVALENT UNIFORM ANNUAL COST
Roofing	1,114,560	1,045,440	3,320,640	5,480,640	603,802
Structural Framing	1,485,728	1,607,027	4,219,513	7,312,268	805,593
Floor *	650,160	609,840	1,646,568	2,906,568	320,217
Foundations	466,490	188,734	623,724	1,278,948	140,902
Exterior Walls	434,016	134,587	715,022	1,283,625	141,417
Interior Walls		1,051,348	4,835,259	5,886,607	648,527
Bridge Crane			1,258,898	1,258,898	138,693
Secure Storage			308,351	308,351	33,971
Total	4,150,954	4,636,976	16,927,975	25,715,905	2,833,121
Equivalent Uniform Annual Cost	457,311	510,856	1,864,955	2,833,121	

* Based on allowable floor loading of 1000 pounds per sq ft

+ Note: Operating area is 30 feet high

TABLE 23

CIVIL ENGINEERING COSTS FOR 60 FOOT BUILDING +

	OPER AREA	MECH AREA	GEN STOR AREA	TOTAL	EQUIVALENT UNIFORM ANNUAL COST
Roofing	1,114,560	1,045,440	3,320,640	5,480,640	608,802
Structural Framing	1,485,728	1,834,365	4,681,400	8,001,493	881,524
Floor *	650,160	609,840	1,646,568	2,906,568	320,217
Foundation	466,490	201,142	641,676	1,309,308	144,246
Exterior Walls	434,016	158,479	834,482	1,426,977	157,210
Interior Walls		1,372,349	6,311,576	7,683,925	846,538
Bridge Crane			1,258,898	1,258,898	138,693
Secure Storage			308,351	308,351	33,971
Total	4,150,954	5,221,615	19,003,591	28,376,160	3,126,202
Equivalent Uniform Annual Cost	457,311	575,265	2,093,626	3,126,202	

* Based on allowable floor loading of 1000 pounds per sq ft

+ Note: Operating area is 30 feet high

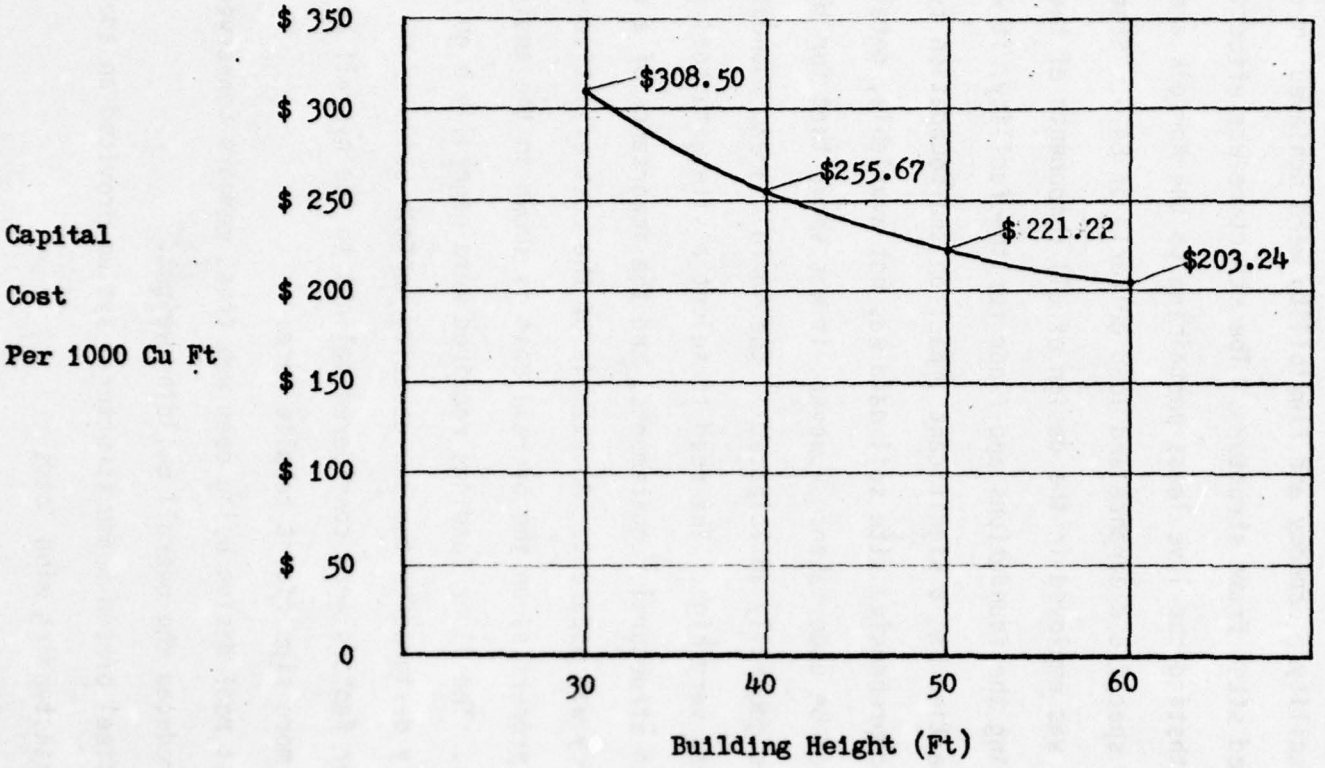


FIGURE 21 CAPITAL COST PER 1000 CU FT VERSUS BUILDING HEIGHT

Conclusions

The objective of the Civil Engineering section was to produce a feasible concept for a structural shell to accommodate the EATG warehouse distribution facility. Economy and flexibility were achieved in the selection of a braced steel frame structure. The structure was effectively designed to withstand the live loads pertaining to the Norfolk area and to fulfill the specific clearance and load criteria of EATG. State of the art technology was employed in the design of all components of the structure.

In designing the foundations and floor for the facility, it was evident that soil properties had a significant impact on the foundation type and cost. Since comprehensive site soil data was not available, detailed design could not be undertaken. However, it was shown that for the poor soil conditions generally anticipated in the Norfolk area, foundation and floor costs were very high. The need to select a site with soil properties compatible with structural requirements, and the importance of a detailed site soil survey was apparent. An example of the cost effectiveness of improved soil properties on the overall cost is shown in the analysis of floor sections. The floor loadings required were generally high and cannot be economically designed on the low capacity Norfolk soil.

Many other factors were considered salient to the overall building concept. The more significant results were:

1. A flat roof design using open web truss members conserved material and reduced the overall building weight.
2. The steel braced frame structural system provided an adequate means of withstanding wind loads.
3. The selection of a low weight structural system had the advantages

of providing adequate earthquake resistance and ensuring minimal foundation loads.

4. Incorporation of a concrete perimeter wall to the 20 foot height was economical and provided the added benefit of security in addition to the primary aim of absorbing part of the wind load.
5. A double rail system through the bridge crane facility was shown to be more economical than a single rail system.
6. The low weight roofing selected was both economical and thermally adequate.

It is emphasized that the design as presented is conceptual rather than detailed. In this regard certain aspects which were a function of the selected site were not addressed. Site preparation, plumbing, provision of personnel support accommodations and other supporting facilities are considered significant. Cost evaluation of these components was specifically site dependent and was considered outside the scope of this analysis. However, standard cost data for these facilities is available and should be incorporated where required.

Recommendations

As a result of this analysis, the following recommendations are pertinent to the facility concept and the selected structural scheme:

1. Engineering parameters should be included with operational and functional requirements in determining suitable facility locations:
   a. Wind loads were a controlling factor in the structural design. Structural economy may be achieved at sites with lower design wind speeds.
   b. Foundation and floor costs may be reduced if soil bearing capacities greater than those assumed for the Norfolk area are available at the selected site. If soil capacities are sufficient to eliminate the need for pile foundations, significant cost savings can be achieved.
2. Functional requirements within the facility should be accurately defined before final design of the facility to avoid possible overdesign and duplication in building capacity:
   a. Reduced column spacing in fixed storage areas or where internal maneuverability requirements are not critical will effectively reduce costs.
   b. Internal fire walls were designed to be non-load-bearing. The load carrying capacity of these walls could be used effectively if their location was fixed.
3. The need for high floor loadings should be well defined and limited to specific areas. The range specified was up to 8000 pounds per square foot and at this loading the requirement for pile foundations results in a high-cost structural floor. Floors with high loadings

are also subject to the possibility of more critical differential settlements which must be accommodated for in the design.

4. A braced steel frame structure with concrete perimeter walls is recommended for its economy and modular layout flexibility.
   a. The braced steel frame structure selected provided a lighter gross building weight than other structures analyzed. This reflected economy of design throughout other components of the building.
   b. The selection of a concrete lift-slab exterior wall provided building security in addition to economy and ease of construction.
5. The cost data produced should be interpreted carefully. Interpolation within the range of heights and floor loads defined is considered reasonable. However, extrapolation to include load data not consistent with the parameters used in the analysis may lead to false conclusions.

III. INTERNAL ENERGY SYSTEMS

Introduction

The efficient use of all energy available to a structure is an important consideration when designing a new facility. This section discusses the electrical and thermal energy systems within the facility and it is the combined effort of the GCE-76S electrical and mechanical engineering teams. Because the electrical and mechanical energy systems are so interrelated, their discussion is combined into an internal energy section.

EATG was responsible for providing the design parameters for the electrical and mechanical systems. GCE-76S developed a design concept and preliminary cost estimates for the internal energy systems based on the given design parameters. It is important to stress that the results presented herein do not constitute a detailed electrical or mechanical design.

In order to develop a design concept it was necessary to determine the energy requirements for the facility. The electrical loads generated by the material handling equipment, the lighting system, and other supporting systems were determined. The heating, ventilating, and air conditioning loads were derived from the external and internal environmental conditions.

After determining the internal energy requirements it was necessary to develop a method to efficiently distribute the thermal and electrical energy throughout the facility. Several typical thermal and electrical energy distribution systems were considered and evaluated. It was also necessary to determine the most economical source of energy. Commercial power, total energy, and solar energy systems were investigated in

conjunction with the various energy distribution and conversion processes. The final internal energy system was selected based on the results of this investigation. Along with determining the most economical energy system, the study includes a brief discussion of how to efficiently operate the energy system by using an energy monitoring and control system.

A design concept and cost estimate for an independent geographically co-located freezer/cooler facility are included in the internal energy section. Basically the same procedures were used to determine the design results for the freezer/cooler facility.

The internal energy system with the lowest life cycle cost was selected. The cost of energy was the singular most important factor in the selection process. A non-inflated and an inflated energy cost was considered. The method used to compute the inflated energy costs is presented in Appendix E-1.

It is important to stress the design and cost results presented are dependent on the design parameters provided by EATG. Any significant change in the level of mechanization would effect the design and cost results.

Material Handling Equipment and Personnel

Three considerations fundamental to the design of the warehouse module, were the definitions of the material handling equipment, manpower, and operating hours projected for the facility. Variables outlined in this section of the report were specified as warehouse requirements by EATG (Mucci, 1976) (Vrba, 1976) (Schwartz, 1976). Material handling equipment requirements are developed in relation to the three functional zones: operating area, mechanized area, and general storage area. This is followed by a discussion of the manpower necessary to support the projected equipment and by a specification of the facility operating hours. One overriding consideration for the evaluation of all information presented in this section is that its only significance is in the definition of a level of technology projected for the warehouse module. Items listed as part of the facility material handling equipment represent no more than a "best guess" at equipment "typical" of the needs of the projected warehouse. These items do not in any way constitute a study of the material handling aspects of the proposed facility. What they do provide is a representation of the projected level of technology, electrical requirements, and heating, ventilation, and air conditioning (HVAC) loads used as a basis for the GCE-76S design study. Substitution of differing types or quantities of material handling equipment possessing electrical and HVAC load requirements similar to those outlined, would not affect the results or validity of this concept design. Further discussion on the effects of changing material handling equipment is given in the "Internal Energy Systems Cost Summary" section of this report.

Operating Area. Equipment used to define the kilowatt and air

conditioning loads for the operating area are listed as follows. Sample calculations for the receiving area conveyors are illustrated in Appendix E-2.

Receiving Area Conveyor	100 HP
Shipping Area Conveyor	100 HP
Care and Preservation Area Conveyor	100 HP
Power and Face Conveyor	90 HP
Set Assembly Conveyor	100 HP
Maintenance Support	450 HP
Container Shop	250 HP
Miscellaneous	300 HP
Total	1490 HP

This horsepower was converted to 1341 kilowatts by using Equation (4).

$$KW = .746 \times HP/Eff \quad (4)$$

where:

KW = Kilowatts

HP = Horsepower

Eff = Motor efficiency

A value of 0.83 was assumed for motor efficiency. This is a typical efficiency for small motors in the one to ten horsepower range (Smeaton, 1969:6-23) which includes the motor sizes associated with the material handling equipment. In addition to the motor loads, computer loads for the operating area were specified. The combined kilowatt loads for motors and computers are listed below.

Motors	1341 KW
Main Computer (IBM 370/158)	70 KW
Intermediate Computer	2 KW

Receiving Mini Computer	3 KW
Packing Mini Computer	1.5 KW
Shipping Mini Computer	1.5 KW
Total	1419 KW

Mechanized Area. The mechanized area was equipped using "typical" systems of bin and rack stacker cranes. The area covered by each system was derived by multiplying the available 40 acres of storage space by factors representing the volume percentages of bin and rack items in the current DOD inventory. These factors were seven percent for bin storage and 19 percent for rack storage. The total mechanized area was equal to 26 percent of 40 acres or 10.4 acres. Thirty-five percent of the 10.4 acres was set aside for support functions such as aisles, processing areas, conveyor lines, office space, and rest rooms. The resulting space requirements are listed below.

Bin Storage = 1.82 acres or 79,279 sq ft

Rack Storage = 4.94 acres or 215,186 sq ft

Support Areas = 3.64 acres or 158,558 sq ft

Mechanized Area = 10.4 acres or 453,024 sq ft

Using bin dimensions of 24 X 18 X 18 inches and rack dimensions of 40 X 48 X 53 inches and stacker crane horizontal speed to vertical speed ratios of 4 to 1, the number of bin and rack aisles, openings, and cranes were computed. A detailed set of sample calculations for the 30 foot building are included in Appendix E-2. In addition to stacker cranes, a total of 390 horsepower was specified for conveyors. Table 24 is a summary of the requirements.

TABLE 24

MECHANIZED AREA HORSEPOWER REQUIREMENTS

HEIGHT (FT)	CONVEYOR HP	NO. OF BIN CRANES	BIN CRANE HP	NO. OF RACK CRANES	RACK CRANE HP	TOTAL HP
30	390	100	1000	130	2600	3990
40	390	70	700	100	2000	3090
50	390	60	600	80	1600	2590
60	390	50	500	65	1300	2190

Table 25 shows the results of converting the horsepower requirements to kilowatts using a motor efficiency of 0.83 and adding a three kilowatt mini computer.

TABLE 25

MECHANIZED AREA KILOWATT REQUIREMENTS

HEIGHT (FT)	KW
30	3594
40	2784
50	2334
60	1974

General Storage Area. Equipment projected for the general storage area included overhead bridge cranes and battery charging equipment for the required fork lifts. The overhead bridge crane requirement, a constant for all building heights, included four-50 horsepower, 60 ton cranes. The total of 200 horsepower represents a 180 kilowatt load. The requirements for battery charging were derived by computing the number of bulk storage line items and then computing the requirements for fork lifts and battery charging based on information provided by EATG (Mucci, 1976)(Vrba, 1976). A sample calculation for the 30 foot building is included in Appendix E-2. Table 26 shows a summary of the general storage area horsepower requirements.

TABLE 26

GENERAL STORAGE AREA HORSEPOWER

BLDG HEIGHT (FT)	NO OF BULK STORAGE LINES	NO OF FORK LIFTS	BATTERY CHARGER	CRANE HORSEPOWER
30	634,710	100	500	200
40	808,515	127	637	200
50	1,064,060	168	839	200
60	1,236,239	195	975	200

Using a motor efficiency of 0.83, the horsepower requirements were converted to kilowatts and added to the battery charger requirements. Table 27 shows the results.

TABLE 27

GENERAL STORAGE AREA

EQUIPMENT KW

BLDG HEIGHT (FT)	KW
30	680
40	817
50	1,019
60	1,155

Manpower Requirements. Manpower requirements make a significant contribution to the HVAC analysis of the GCE-76S study. Both the number of personnel assigned and shift scheduling were important factors. EATG specified the operating area requirement as 1,406 people. The mechanized area requirements were computed on the basis of one person for each bin or rack aisle and general storage area requirements were based on Air Force Logistics Command (AFLC) ratios for manpower required versus line items in bulk storage (Mucci, 1976). A summary of the personnel requirements is shown in Table 28.

TABLE 28

MANPOWER REQUIREMENTS

BLDG HEIGHT (FT)	OPER AREA (PEOPLE)	MECH AREA (PEOPLE)	GEN STOR AREA (PEOPLE)	TOTAL (PEOPLE)
30	1,406	288	317	2,011
40	1,406	213	404	2,023
50	1,406	175	532	2,113
60	1,406	144	618	2,168

Work schedules were divided into two categories, weekdays, and weekend/holidays. The specified work schedule for each category is shown in Table 29.

TABLE 29

WORK SCHEDULES

HOURS OF DAY	WEEKDAY PERCENT OF WORKFORCE	WEEKEND/HOLIDAY PERCENT OF WORKFORCE
0000-0800	0	0
0800-1600	80	20
1600-1700	100	20
1700-2400	20	0

Facility Operating Hours. Specifications of the annual operating hours for the facility were important in the computation of accurate

electrical and HVAC consumption data and costs. Two day types were used, normal weekday workdays, and weekend/holiday workdays. As shown in the section above on manpower requirements, two work shifts were specified for weekdays and one work shift was specified for weekend/holidays. The weekday schedule included a full capacity day shift from 0800 hours to 1700 hours and a 20 percent night shift from 1600 hours to 2400 hours. The weekend/holiday scheduled was for just one, 20 percent, day shift from 0800 hours to 1700 hours. A monthly listing of the number of each day type is shown in Table 30.

TABLE 30

MONTHLY DAY TYPE DISTRIBUTION

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Weekdays	21	19	23	22	20	22	21	22	21	19	21	20	251
Weekend/Holidays	10	9	8	8	11	8	10	9	9	12	9	11	114

Lighting Design

The lighting design can directly affect the morale and productivity of the individual worker. It is necessary to provide an adequate level of illumination so that tasks may be performed with speed and accuracy. In addition, the design must provide a uniform lighting level that results in maximum safety and an absence of visual discomfort to the worker. The design must provide this level of lighting throughout the life of the facility.

In designing a lighting system, economics is a major consideration. The increasing incentives to conserve energy make it imperative to insure that the energy used to power the lights is used efficiently. When considering economics, the initial cost and the operations and maintenance cost must be determined.

When designing a lighting system, design standards must be followed. In this study the design procedures recommended by the Illuminating Engineering Society (IES) were used to insure that an adequate and uniform lighting level is maintained in each area of the facility. The life cycle costs for high pressure sodium (HIDSOD), mercury vapor (MERC), and metal halide (METHAL) lighting systems were considered for each area of the building.

This portion of the design study describes the design approach used to determine the most economical lighting system. The design input and the design results are presented and finally, a list of recommendations is provided.

Design Approach and Input Data. The primary consideration in designing the lighting system was to provide an adequate level of illumination for

the smallest life cycle cost. The lighting system was designed to provide the necessary illumination level evenly throughout each section of the facility. The lumen method was used in the design. The lumen method and how it applies to this particular design are discussed in detail.

The first step of the design procedure was to determine the required level of illumination for each area of the facility. The facility was broken into the following six lighting design zones: see Figure 22 for the lighting design zones.

1. Operating Area
2. Mechanized Area
3. General Storage Area
4. Cooler Area
5. Freezer Area
6. Freezer/Cooler Vestibule

It was necessary to assume the type of activity that would be performed in each of the lighting design zones in order to determine the level of illumination in footcandles. The values for the levels of illumination used in this study were those recommended by the IES (IES, 1972:9.81-9.91) and coincided with the levels of illumination recommended by Westinghouse Electric Company (Westinghouse, 1969:5.11-5.13). In addition, these levels of illumination are currently used by the Air Force (AFM 88-15, 1975: 7.2). The type activity and associated levels of illumination are shown in Table 31.

Second, the type of luminaire and lamp was selected. The Duraglow luminaire manufactured by General Electric was selected for the investigation. The Duraglow luminaire is recommended for use in warehouses

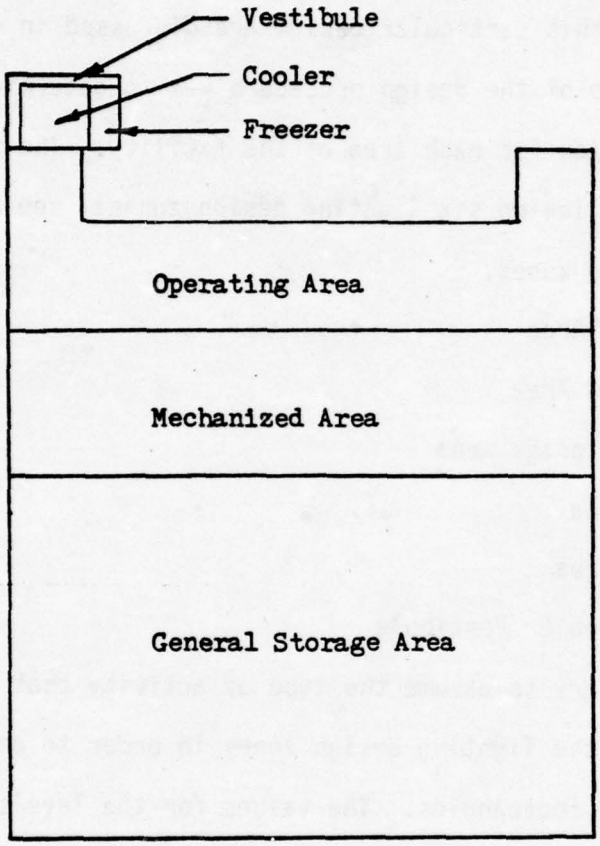


FIGURE 22 LIGHTING DESIGN ZONES

TABLE 31

LIGHTING DESIGN ZONE ACTIVITY AND ILLUMINATION LEVELS

AREA	ASSUMED TYPE OF ACTIVITY	LEVEL OF ILLUMINATION (FOOT-CANDLES)
Operating Area	Materials Handling Area Shipping, Receiving, Labeling, & Packing of Items	50
Mechanized Area	Active Storage Area Majority of Items Medium Size	20
General Storage Area	Active Storage Area Bulk Storage, Majority of Items Medium Size	20
Cooler Area	Active Storage Area Cold Storage, Small to Medium Size	20
Freezer Area	Active Storage Area Freezer, Small to Medium Sized Items	20
Freezer/ Cooler Vestibule	Materials Handling Area Shipping, Receiving, Labeling & Packing of Items	50

(GE, 1974b:32). In addition, the photometric data published by General Electric is considered reliable (Geers, 1976).

The three types of high intensity discharge (HID) lamps evaluated in the study were the HIDSOD, MERC, and METHAL lamps. The HIDSOD lighting system proved to be the most economical lighting system because of the high lumen output and long life. The design comparison between HIDSOD, MERC, and METHAL is shown in Appendix E-5.

The HIDSOD does emit most of its lighting energy in a small wave band. The normal visual spectrum is approximately 350 to 750 nanometers. HIDSOD gives off most of its energy in the range of 560 to 625 nanometers (IES, 1972:8.20). This affects the color rendition only slightly. HIDSOD lamps have been used successfully in industrial applications and even in offices with no complaints concerning the color rendition.

Another advantage of HIDSOD lamps is their relatively short restrike time. Because the restrike time is less than one minute a standby lighting system is not required (GE, 1975a:5). In addition, the warm up time to 80 percent light output is three to four minutes (GE, 1975a:5). However, on initial starting the lamp does give off some light.

Fluorescent luminaires and lamps were also considered for the design, but were ruled out early in the study. The fluorescent system had a high initial cost due to the large number of luminaires required because of the high mounting heights. The maintenance cost for a fluorescent system was also significantly higher, primarily due to the short life of the lamps. The large number of lamps increased operating costs because they use more electricity.

After determining the levels of illumination and selecting the

luminaire and lamps, the third step in the design process was to determine a coefficient of utilization. The coefficient of utilization is a ratio of the amount of light reaching the work plane to the amount of light generated by the lamps. Since this factor is determined by the efficiency of the luminaire, the mounting height, the room proportions, and the reflectances of the walls, ceiling, and floors, it was necessary to develop a lighting design model and account for the various factors mentioned.

The efficiency of the luminaire was determined from manufacturers data which matched the Duraglow luminaire specifically with the type lamp used.

The height from the floor to the bottom of the luminaire is 30 feet in each section for the 30 foot facility. The height was increased at 10 foot increments in the storage area for the 40, 50, and 60 foot facility. The depth of the ceiling cavity was assumed to be five feet in all cases, while the work plane was assumed to be 2.5 feet above the floor: see Figure 23 for the design model for the different ceiling heights.

The design area was assumed to be empty. Since neither the rack sizes nor the commodity types were known, an exact aisle spacing could not be determined. Therefore, the design did not consider the vertical illumination on the aisles or stacks. In addition, the study group did not have adequate information to assume where the interior fire walls will be placed in the building. Their affect on the room proportions could not be calculated.

The size of each design area was large. Realizing that light from a luminaire would have little or no effect on the work plane at distances

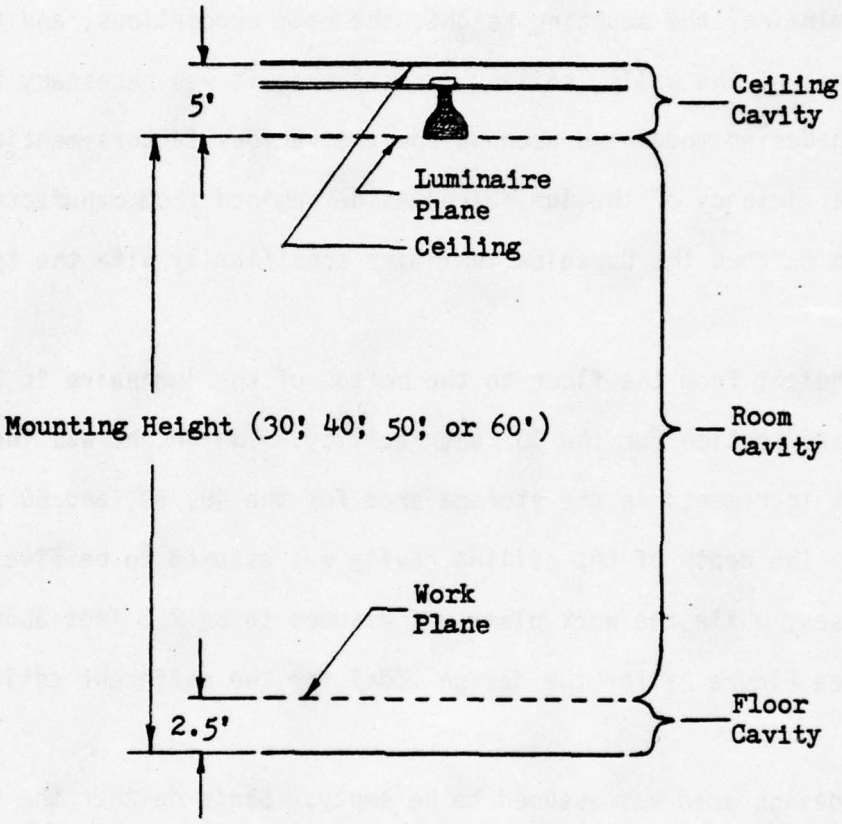


FIGURE 23 LIGHTING DESIGN MODEL

greater than approximately 100 feet, each large area was broken into smaller room cavities. Although there was no wall to reflect the light it was assumed that the reflectance values of these room cavities was the same as for a white wall. This assumption is reasonable since the surrounding wall cavities would contribute light to adjacent room cavities.

The floor reflectance value was assumed to be 20 percent and the wall reflectance value was assumed to be 50 percent. The ceiling reflectance value was assumed to be 80 percent and this value was based on a white ceiling and was corrected for the fact that the luminaire was assumed to be mounted five feet below the ceiling. See Appendix E-3 for the calculation of the coefficient of utilization.

The fourth step in the design procedure was to determine the light loss factor. The lighting output of a lighting system decreases with time. This decrease in lighting output is accounted for by the light loss factor. This factor is made up of several contributing factors, three of which significantly affected this design. The lamp lumen depreciation factor accounts for a reduction in lumen output as the lamp burns through its life. The luminaire dirt depreciation factor accounts for the fact that dirt collects on the lamp and luminaire, thus reducing the lighting efficiency. Lamp outages decrease the level of illumination in direct proportion to the number of lamp outages that occur. The light loss factors were obtained from manufacturers' data.

The final step in the design process was to determine the number of lamps and luminaires required. Since there is one lamp per luminaire, the number of lamps and luminaires can be calculated from the following formula:

Number of lamps = Fc X A/LL X CU X LLF (5)

where:

Fc = The level of illumination

A = The total design area

LL = The initial lumen output per lamp

CU = The coefficient of utilization

LLF = The light loss factor

A summary of the design input data for each building is presented in Tables 32, 33, 34, and 35.

Cost Input Data. In order to determine the lowest life cycle cost it was necessary to develop a method to determine the initial cost and the operating and maintenance costs. The cost development is discussed in this section.

The initial lighting system costs include the luminaire cost, lamp cost, accessory cost, hanging cost, outlet cost, and the circuit costs plus the installation costs. The luminaire and lamp costs were obtained from manufacturers catalogs. Catalog prices, however, are not representative for large volume purchases; therefore, a correction factor was considered. The initial cost used in the study was the catalog price multiplied by a 0.50 correction factor (Geers, 1976).

The lighting system was designed using a busway circuit. The busway circuit provides flexibility by allowing the luminaire to be moved along the busway as the configuration of aisles and stacks within the facility change. The cost of the busway system was compared to the cost of using wire circuits and the busway circuit was only slightly more expensive. Appendix E-4 shows the cost results comparing the busway and wire circuits.

The circuit costs for the busway circuit include all the costs from the substation to the luminaire. The luminaires and lamps are installed with the busway, therefore, the installation cost of the busway includes the hanging costs for the luminaires and lamps. The outlet cost for the busway circuit is also included in the circuit cost. In a wire circuit the cost to hang the luminaires and lamps plus an outlet cost must be added.

The accessory cost includes items such as hooks and plugs which were not included in the luminaire cost. The busway costs and accessory costs were obtained from manufacturer's catalogs and the 0.50 correction factor was applied.

The operations and maintenance cost includes the cost of labor and material to spot replace burned out lamps. Also included is the material and labor cost to replace ballasts. In order to maintain an effective lighting level it is necessary to clean the luminaires and lamps every three years. This cost has also been included. The energy cost was considered when selecting the most efficient lighting system; however, in the final results the energy costs are presented in the Internal Energy System Costs section of this report.

The cost input data for the HIDSOD lighting system is shown in Tables 36, 37, 38, and 39.

Design and Cost Results. The LGHTECON computer program was used to determine the design and circuit results (Geers, 1975). This section will discuss how the results were obtained and present the results in tabular form.

It was necessary to make an initial run with LGHTECON to determine the design results. After the design results were obtained, a circuit

cost was calculated. LGHTECON was run again to obtain the cost results. These results were then converted into an annual cost.

To convert the initial cost results to an annual cost a 25 year system life was assumed. The interest rate was 10 percent and it was assumed that the system had no salvage value after the 25 years. The operating and maintenance costs were averaged over 25 years. The cost of energy is not included in the total operating costs. This cost appears in the Internal Energy System Cost section of this report. In addition, the cost of special highlift equipment required to reach the luminaires for cleaning and maintenance was not included.

The design and cost results are shown for each building in Tables 40, 41, 42, and 43.

Recommendations. After completing the study of the lighting system, the following items are recommended:

1. A HIDSOD lighting system should be used. Such a system is more economical than other lighting systems when comparing life cycle costs especially, in energy savings.
2. The lighting design of the actual facility must consider the functional layout of the facility and be designed accordingly. Vertical illumination levels must be considered, especially where high racks are used.
3. Busway circuits should be used to add flexibility to the lighting system. Wire circuits initially cost less than a busway circuit. However, should the functional plan of the facility change within its life, it would be much more costly to rearrange the wire circuits than simply move the luminaires along the busway circuits.

4. To insure maximum energy savings the lighting system should be connected to an energy monitoring and control system. This would help insure that the lights are off in certain areas of the building when these areas are not in use.

TABLE 32

LIGHTING DESIGN INPUT DATA FOR 30 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Total Length	1,320	1,320	150	150	395
Total Width	330	1,320	75	150	20
Design Area	435,600	1,742,400	11,250	22,500	7,900
Room Cavity Width	110	110	75	75	20
Room Cavity Length	110	110	75	75	98.8
Effective Ceiling Reflectance	73	73	70	70	61
Wall Reflectance	50	50	50	50	50
Floor Reflectance	20	20	20	20	20
Design Illumination Level (FC)	50	20	20	20	50
Lamp	400W HIDSOD	400W HIDSOD	250W HIDSOD	250W HIDSOD	400W HIDSOD
Luminaire	DURAGLOW	DURAGLOW	DURAGLOW	DURAGLOW	DURAGLOW
Initial Lumens Per Lamp	50,000	50,000	30,000	30,000	50,000
Initial Life (Hrs)	20,000	20,000	15,000	15,000	20,000
Coefficient Of Utilization	0.80	0.800	0.767	0.767	0.800
Ballast Life At Ambient Temperature	100,000	100,000	100,000	100,000	100,000
Lamp Lumen Depreciation Factor	0.900	0.900	0.910	0.910	0.900
Lamp Temperature Depreciation Factor	1.000	1.000	1.000	1.000	1.000

TABLE 32 CONTINUED

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Lamp Dirt Depreciation Factor	0.840	0.840	0.840	0.840	0.840
Light Loss Factor	0.756	0.756	0.764	0.764	0.756
System Voltage (Volts)	277	277	277	277	277
Maximum Current Per Circuit (Amps)	24	24	24	24	24

TABLE 33

LIGHTING DESIGN INPUT DATA FOR 40 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Total Length	1,320	1,320	150	150	395
Total Width	330	1,320	75	150	20
Design Area	435,600	1,742,400	11,250	22,500	7,900
Room Cavity Width	110	110	75	75	20
Room Cavity Length	110	110	75	75	98.8
Effective Ceiling Reflectance	73	73	70	70	61
Wall Reflectance	50	50	50	50	50
Floor Reflectance	20	20	20	20	20
Design Illumination Level (FC)	50	20	20	20	50
Lamp	400W HIDSOD	400W HIDSOD	250W HIDSOD	250W HIDSOD	400W HIDSOD
Luminaire	DURAGLOW	DURAGLOW	DURAGLOW	DURAGLOW	DURAGLOW
Initial Lumens Per Lamp	50,000	50,000	30,000	30,000	50,000
Initial Life (Hrs)	20,000	20,000	15,000	15,000	20,000
Coefficient Of Utilization	0.80	0.741	0.767	0.767	0.800
Ballast Life At Ambient Temperature	100,000	100,000	100,000	100,000	100,000
Lamp Lumen Depreciation Factor	0.900	0.900	0.910	0.910	0.900
Lamp Temperature Depreciation Factor	1.000	1.000	1.000	1.000	1.000

TABLE 33 CONTINUED

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Lamp Dirt Depreciation Factor	0.840	0.840	0.840	0.840	0.840
Light Loss Factor	0.756	0.756	0.764	0.764	0.764
System Voltage (Volts)	277	277	277	277	277
Maximum Current Per Circuit (Amps)	24	24	24	24	24

TABLE 34

LIGHTING DESIGN INPUT DATA FOR 50 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Total Length	1,320	1,320	150	150	395
Total Width	330	1,320	75	150	20
Design Area	435,600	1,742,400	11,250	22,500	7,900
Room Cavity Width	110	110	75	75	20
Room Cavity Length	110	110	75	75	98.8
Effective Ceiling Reflectance	73	73	70	70	61
Wall Reflectance	50	50	50	50	50
Floor Reflectance	20	20	20	20	20
Design Illumination Level (FC)	50	20	20	20	50
Lamp	400W HIDSOD	400W HIDSOD	250W HIDSOD	250W HIDSOD	400W HIDSOD
Luminaire	DURAGLOW	DURAGLOW	DURAGLOW	DURAGLOW	DURAGLOW
Initial Lumens Per Lamp	50,000	50,000	30,000	30,000	50,000
Initial Life (Hrs)	20,000	20,000	15,000	15,000	20,000
Coefficient Of Utilization	0.800	0.692	0.767	0.767	0.800
Ballast Life At Ambient Temperature	100,000	100,000	100,000	100,000	100,000
Lamp Lumen Depreciation Factor	0.900	0.900	0.910	0.910	0.900
Lamp Temperature Depreciation Factor	1.000	1.000	1.000	1.000	1.000

TABLE 34 CONTINUED

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Lamp Dirt Depreciation Factor	0.840	0.840	0.840	0.840	0.840
Light Loss Factor	0.756	0.756	0.764	0.764	0.764
System Voltage (Volts)	277	277	277	277	277
Maximum Current Per Circuit (Amps)	24	24	24	24	24

TABLE 35

LIGHTING DESIGN INPUT DATA FOR 60 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Total Length	1,320	1,320	150	150	395
Total Width	330	1,320	75	150	20
Design Area	435,600	1,742,400	11,250	22,500	7,900
Room Cavity Width	110	110	75	75	20
Room Cavity Length	110	110	75	75	98.8
Effective Ceiling Reflectance	73	73	70	70	61
Wall Reflectance	50	50	50	50	50
Floor Reflectance	20	20	20	20	20
Design Illumination Level (FC)	50	20	20	20	50
Lamp	400W HIDSOD	1000W HIDSOD	250W HIDSOD	250W HIDSOD	400W HIDSOD
Luminaire	DURAGLOW	DURAGLOW	DURAGLOW	DURAGLOW	DURAGLOW
Initial Lumens Per Lamp	50,000	140,000	30,000	30,000	50,000
Initial Life (Hrs)	20,000	15,000	15,000	15,000	20,000
Coefficient Of Utilization	0.800	0.577	0.767	0.767	0.800
Ballast Life At Ambient Temperature	100,000	100,000	100,000	100,000	100,000
Lamp Lumen Depreciation Factor	0.900	0.920	0.910	0.910	0.900
Lamp Temperature Depreciation Factor	1.000	1.000	1.000	1.000	1.000

TABLE 35 CONTINUED

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Lamp Dirt Depreciation Factor	0.840	0.840	0.840	0.840	0.840
Light Loss Factor	0.756	0.773	0.764	0.764	0.764
System Voltage (Volts)	277	277	277	277	277
Maximum Current Per Circuit (Amps)	24	24	24	24	24

TABLE 36

LIGHTING COST INPUT DATA FOR 30 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Burning Hrs. Per Start	16	16	16	16	16
Annual Burning Hours	4,992	4,992	4,992	4,992	4,992
Energy Rate *	0.0441	0.0441	0.0441	0.0441	0.0441
Circuit Cost **	1326.00	2067.00	1122.00	1640.00	1096.00
Initial Luminaire Cost (Includes Ballast) +	104.00	104.00	96.00	96.00	104.00
Initial Lamp Cost +	30.00	30.00	32.00	32.00	30.00
Accessory Cost +	7.60	7.60	7.60	7.60	7.60
Outlet Cost	0.00	0.00	0.00	0.00	0.00
Hanging Cost	0.00	0.00	0.00	0.00	0.00
Replacement Ballast Cost ++	90.00	90.00	90.00	90.00	90.00
Labor To Replace Ballast Δ	15.00	15.00	15.00	15.00	15.00
Replacement Lamp Cost +	24.00	24.00	25.60	25.60	24.00
Labor To Spot Relamp Δ	3.00	3.00	3.00	3.00	3.00
Cost To Clean Luminaire Δ	3.00	3.00	3.00	3.00	3.00

+ (GE, 1975b: 9,20,22)

++ (GE, 1974a)

Δ (Geers, 1976)

* See Appendix E-1

** See Appendix E-4

TABLE 37

LIGHTING COST INPUT DATA FOR 40 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Burning Hrs. Per Start	16	16	16	16	16
Annual Burning Hours	4,992	4,992	4,992	4,992	4,992
Energy Rate *	0.0441	0.0441	0.0441	0.0441	0.0441
Circuit Cost **	1326.00	2113.00	1122.00	1640.00	1096.00
Initial Luminaire Cost (Includes Ballast) +	104.00	104.00	96.00	96.00	104.00
Initial Lamp Cost +	30.00	30.00	32.00	32.00	30.00
Accessory Cost +	7.60	7.60	7.60	7.60	7.60
Outlet Cost	0.00	0.00	0.00	0.00	0.00
Hanging Cost	0.00	0.00	0.00	0.00	0.00
Replacement Ballast Cost ++	90.00	90.00	90.00	90.00	90.00
Labor To Replace Ballast Δ	15.00	15.00	15.00	15.00	15.00
Replacement Lamp Cost +	24.00	24.00	25.60	25.60	24.00
Labor To Spot Relamp Δ	3.00	3.00	3.00	3.00	3.00
Cost To Clean Luminaire Δ	3.00	3.00	3.00	3.00	3.00

+ (GE, 1975b:9,20,22)

++ (GE, 1974a)

Δ (Geers, 1976)

* See Appendix E-1

** See Appendix E-4

TABLE 38

LIGHTING COST INPUT DATA FOR 50 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Burning Hrs. Per Start	16	16	16	16	16
Annual Burning Hours	4,992	4,992	4,992	4,992	4,992
Energy Rate *	0.0441	0.0441	0.0441	0.0441	0.0441
Circuit Cost **	1326.00	2238.00	1122.00	1640.00	1096.00
Initial Luminaire Cost (Includes Ballast) +	104.00	104.00	96.00	96.00	104.00
Initial Lamp Cost +	30.00	30.00	32.00	32.00	30.00
Accessory Cost +	7.60	7.60	7.60	7.60	7.60
Outlet Cost	0.00	0.00	0.00	0.00	0.00
Hanging Cost	0.00	0.00	0.00	0.00	0.00
Replacement Ballast Cost ++	90.00	90.00	90.00	90.00	90.00
Labor To Replace Ballast Δ	15.00	15.00	15.00	15.00	15.00
Replacement Lamp Cost +	24.00	24.00	25.60	25.60	24.00
Labor To Spot Relamp Δ	3.00	3.00	3.00	3.00	3.00
Cost To Clean Luminaire Δ	3.00	3.00	3.00	3.00	3.00

+ (GE, 1975b:9,20,22)

++ (GE, 1974a)

Δ (Geers, 1976)

* See Appendix E-1

** See Appendix E-4

TABLE 39

LIGHTING COST INPUT DATA FOR 60 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER	COOLER	VESTIBULE
Burning Hrs Per Start	16	16	16	16	16
Annual Burning Hours	4,992	4,992	4,992	4,992	4,992
Energy Rate *	0.0441	0.0441	0.0441	0.0441	0.0441
Circuit Cost **	1326.00	1764.00	1122.00	1640.00	1096.00
Initial Luminaire Cost (Includes Ballast) +	104.00	149.00	96.00	96.00	104.00
Initial Lamp Cost +	30.00	69.00	32.00	32.00	30.00
Accessory Cost +	7.60	7.60	7.60	7.60	7.60
Outlet Cost	0.00	0.00	0.00	0.00	0.00
Hanging Cost	0.00	0.00	0.00	0.00	0.00
Replacement Ballast Cost ++	90.00	90.00	90.00	90.00	90.00
Labor To Replace Ballast Δ	15.00	15.00	15.00	15.00	15.00
Replacement Lamp Cost +	24.00	55.20	25.60	25.60	24.00
Labor To Spot Relamp Δ	3.00	3.00	3.00	3.00	3.00
Cost To Clean Luminaire Δ	3.00	3.00	3.00	3.00	3.00

+ (GE, 1975b:9,20,22)

++ (GE, 1974a)

Δ(Geers, 1976)

* See Appendix E-1

** See Appendix E-4

TABLE 40

DESIGN AND COST RESULTS FOR 30 FOOT BUILDING

ITEM	OPER AREA	MECH AREA	GEN STOR AREA	FREEZER/ COOLER AND VESTIBULE
No. Of Luminaires	721	333	1,000	62
No. Of Circuits	53	24	73	5
Load In Kilowatts	347.5	138.9	416.8	23.1
Luminaire Cost	74,984.00	29,978.00	89,934.00	6,136.00
Accessory Cost	5,479.60	2,190.70	6,572.10	471.20
Lamp Cost	21,630.00	8,647.50	25,942.50	1,938.00
Circuit Cost	70,278.00	43,412.75	130,238.25	6,594.00
Total Initial Cost	172,371.60	84,228.95	252,686.85	15,139.20
Initial Annual Cost	18,990.18	9,279.50	27.838.51	1,667.89
Spot Relamping Cost	4,858.96	1,942.58	5,827.73	526.21
Ballast Replacement Cost	3,779.19	1,510.89	4,532.67	324.98
Cleaning Cost	539.88	215.84	647.53	56.16
Energy Cost *	36,431.43	14,564.99	43,692.72	2,417.32
Total O & M Cost	45,609.46	18,234.30	54,700.65	3,324.67
Total System Annual Cost*	28,168.21	12,948.81	38,846.44	2,575.24
Total System Cost Per 1000 Cu Ft	2.16	0.99	0.99	2.06

* Energy Cost Not Included In Total System Costs

TABLE 41

DESIGN AND COST RESULTS FOR 40 FOOT BUILDING

ITEM	OPER AREA	MECH AREA	GEN STOR AREA	FREEZER/ COOLER AND VESTIBULE
No. Of Luminaires	721	311	934	62
No. Of Circuits	53	23	68	5
Load In Kilowatts	347.5	150.0	450.1	23.1
Luminaire Cost	74,984.00	32,370.00	98,110.00	6,136.00
Accessory Cost	5,479.60	2,365.50	7,096.50	471.20
Lamp Cost	21,630.00	9,337.50	28,012.50	1,938.00
Circuit Cost	70,278.00	48,070.75	144,212.25	6,594.00
Total Initial Cost	172,371.60	92,143.75	276,431.25	15,139.20
Initial Annual Cost	18,990.18	10,151.48	30,454.43	1,667.89
Spot Relamping Cost	4,858.96	2,097.58	6,292.73	526.21
Ballast Replacement Cost	3,779.19	1,631.45	4,894.34	324.98
Cleaning Cost	539.88	233.07	699.20	56.16
Energy Cost *	36,431.43	15,727.16	47,181.47	2,417.32
Total O & M Cost	45,609.46	19,689.26	59,067.74	3,324.67
Total System Annual Cost*	28,168.21	14,113.58	42,340.70	2,575.24
Total System Cost Per 1000 Cu Ft	2.16	0.81	0.81	2.06

* Energy Cost Not Included In Total System Costs

TABLE 42

DESIGN AND COST RESULTS FOR 50 FOOT BUILDING

ITEM	OPER AREA	MECH AREA	GEN STOR AREA	FREEZER/ COOLER AND VESTIBULE
No. Of Luminaires	721	333	1,000	62
No. Of Circuits	53	24	73	5
Load In Kilowatts	347.5	160.6	481.9	23.1
Luminaire Cost	74,984.00	34,658.00	103,974.00	6,136.00
Accessory Cost	5,479.60	2,532.70	7,598.10	471.20
Lamp Cost	21,630.00	9,997.50	29,992.50	1,938.00
Circuit Cost	70,278.00	54,271.50	162,814.50	6,594.00
Total Initial Cost	172,371.60	101,459.70	304,379.10	15,139.20
Initial Annual Cost	18,990.18	11,177.82	33,533.45	1,667.89
Spot Relamping Cost	4,858.96	2,245.84	6,737.51	526.21
Ballast Replacement Cost	3,779.19	1,746.76	5,240.29	324.98
Cleaning Cost	539.88	249.54	748.61	56.16
Energy Cost *	36,431.43	16,838.80	50,516.39	2,417.32
Total O & M Cost	45,609.46	21,080.94	63,242.80	3,324.60
Total System Annual Cost*	28,168.21	15,419.96	46,259.86	2,575.24
Total System Cost Per 1000 Cu Ft	2.16	0.71	0.71	2.06

* Energy Cost Not Included In Total System Costs

TABLE 43

DESIGN AND COST RESULTS FOR 60 FOOT BUILDING

ITEM	OPER AREA	MECH AREA	GEN STOR AREA	FREEZER/ COOLER AND VESTIBULE
No. Of Luminaires	721	140	419	62
No. Of Circuits	53	24	72	5
Load In Kilowatts	347.5	157.9	473.8	23.1
Luminaire Cost	74,984.00	20,822.75	62,468.25	6,136.00
Accessory Cost	5,479.60	1,062.10	3,186.30	471.20
Lamp Cost	21,630.00	9,642.75	28,928.25	1,938.00
Circuit Cost	70,278.00	42,336.00	127,008.00	6,594.00
Total Initial Cost	172,371.60	73,863.60	221,590.80	15,139.20
Initial Annual Cost	18,990.18	8,137.55	24,412.66	1,667.89
Spot Relamping Cost	4,858.96	2,706.81	8,120.44	526.21
Ballast Replacement Cost	3,779,19	732.51	2,197.54	324.98
Cleaning Cost	539.88	139.53	418.58	56.16
Energy Costs	36,431.43	16,554.81	49,664.42	2,417.32
Total O & M Cost	45,609.46	20,133.66	60,400.98	3,324.67
Total System Annual Cost*	28,168.21	11,716.40	35,151.22	2,575.24
Total System Cost Per 1000 Cu Ft	2.16	0.45	0.45	2.06

* Energy Cost Not Included In Total System Cost

Emergency Lighting System

In the event of an electrical power failure or an emergency situation that would result in the loss of the primary lighting system, it is necessary to provide an emergency lighting system so that personnel working in the facility can evacuate rapidly and safely. This section deals with the design and cost of a reliable emergency lighting system. The design criteria are established and the emergency lighting system that was selected is discussed. A discussion of how the costs for the emergency lighting system were developed is presented.

Design Criteria. In order to design an emergency lighting system for the facility, it was necessary to establish some design criteria. Basically, the criteria was divided into three major areas; the level of illumination required, the circuit design criteria, and the criteria for the selection of an emergency power source.

It is necessary to provide an adequate level of illumination so that personnel within the facility can egress safely in the event the primary lighting system fails. Enough light must be provided so that personnel are able to determine a route of egress and discern any object that may block that path. The level of illumination recommended for safe egress is one foot-candle (NFPA, 1973:48).

Branch circuits must be installed in order to service the emergency lighting system when the main source of power is interrupted. The emergency lighting circuit wiring must be kept entirely independent of all other wiring. This means that the emergency wiring cannot enter the same raceway, conduit, or panel box with other wire (NEC, 1974:70-516).

An emergency source of power must be used to supply electricity to

the emergency lights. The emergency power source must supply usable power to the emergency lighting system within ten seconds and must be capable of supplying sufficient power for at least 30 minutes (NFPA, 1973:49).

System Selection and Design. Two types of emergency lighting systems were considered. The first was to provide emergency lighting using wall mounted, battery operated spotlights throughout the building. The second system was to provide emergency lighting using ceiling mounted luminaires powered by a centrally located battery bank or a quick-start diesel generator.

The wall mounted spotlight system was found to be impractical. In order to provide one foot-candle level of illumination, the wall mounted spotlights could not be mounted higher than ten feet on the walls and columns throughout the facility; therefore, being subject to damage by fork lifts plus blockage by bins and racks. To overcome this problem a large number of units would be required, thus increasing the cost of the system. The second major drawback is the high maintenance cost associated with these wall mounted units. The units must be inspected frequently and bad battery packs must be replaced (Geers, 1976).

The ceiling mounted luminaires were found to be practical and economical. The emergency lighting system makes use of the Duraglow luminaires selected for the high pressure sodium lighting system. The luminaire can be ordered with an emergency lighting option. A single ended quartz lamp is placed in the same reflector with the high pressure sodium lamp. The wiring for the quartz lamp is completely independent of the high pressure sodium system; therefore, it meets the emergency circuit design criteria.

In order to design the emergency lighting system several assumptions were made. Since the configuration of the aisles in the warehouse was not known, the emergency lighting system was designed to provide one foot-candle of illumination over the entire facility. It was assumed that no outside source of light through windows, doors, and skylights would be available. The lighting design model described in the "Lighting Design" section of this report was used. The luminaire design data used for the emergency lighting system is summarized for each building height in Tables 44, 45, 46, and 47.

The LGHTECON computer program was used to determine the number of luminaires and circuits required for the emergency lighting system design (see Tables 44, 45, 46, and 47). One foot-candle of illumination was obtained in all areas except in the general storage and mechanized areas for the 60 foot building. Because of the ceiling heights and because the 1000 watt high pressure sodium lamp decreased the number of luminaires used, only a 0.70 foot-candle level of illumination could be obtained. This level of illumination is adequate since the luminaire arrangement can be adjusted to provide at least one foot-candle of illumination along egress routes.

The circuits for the emergency lighting system are completely separate from the primary lighting system circuits. The circuits consist of wire in conduit and the circuit arrangement is shown in Figure 24. The circuit design calculations are presented in Appendix E-7.

Two methods of supplying electrical power to the emergency lighting system were investigated. The first system investigated was an uninterruptable power supply (UPS) consisting of a large storage battery and a device

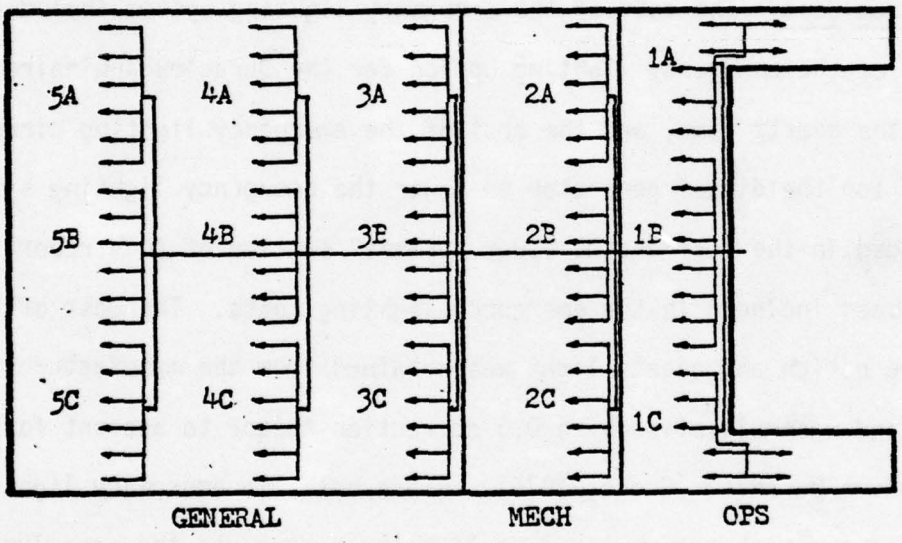


FIGURE 24 EMERGENCY LIGHTING CIRCUIT ARRANGEMENT

to convert DC energy into 60 cycle AC energy. The second system investigated was to use a diesel generator equipped with an automatic transfer switch that can respond to a commercial power failure and be on line within ten seconds. The diesel generator proved to be more economical than the UPS system. The diesel generator used to power the emergency lighting system is a part of the back-up power system as described in the "Commercial Power Systems" section of this report.

System Cost. The cost of the emergency lighting system includes the cost of the emergency lighting option for the Duraglow luminaire, the cost of the quartz lamp, and the cost of the emergency lighting circuit. The cost for the diesel generator to power the emergency lighting system is included in the "Commercial Power Systems" section of this report and has not been included in the emergency lighting costs. The cost of the luminaire option and quartz light was obtained from the manufacturer's catalog and was multiplied by a 0.5 correction factor to account for a large volume purchase (Geers, 1976). Since both the emergency lighting system and the high pressure sodium lighting system use the same luminaire, the installation cost for the emergency lighting system luminaires and lamps is included in the high pressure sodium system installation cost as described in the "Lighting Design" section of this report. The circuit cost development is presented in Appendix E-7.

Table 48 shows the cost input data for the emergency lighting system. The cost results for each building are presented in Tables 49, 50, 51, and 52. The initial cost of the emergency lighting system is converted to an annual cost assuming a zero salvage value after 25 years. Since the emergency lighting system was assumed to operate less than ten hours

a year, the operations and maintenance costs are insignificant and are not included in the study.

TABLE 44

EMERGENCY LIGHTING INPUT DATA FOR 30 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER AREA	COOLER AREA	VESTIBULE
Total Length	1,320	1,320	150	150	395
Total Width	330	1,320	75	150	20
Room Cavity Length	110	110	75	75	98.8
Room Cavity Width	110	110	75	75	20
Effective Ceiling Reflectance	73	73	70	70	61
Wall Reflectance	50	50	50	50	50
Floor Reflectance	20	20	20	20	20
Design Illumination Level (FC)	1	1	1	1	1
Lamp Type	250W Quartz	250W Quartz	150W Quartz	150W Quartz	250W Quartz
Initial Lumens Per Lamp	4,850	4,850	2,900	2,900	4,850
Coefficient Of Utilization	0.800	0.800	0.767	0.767	0.472
Lamp Lumen Depreciation Factor	0.970	0.970	0.970	0.970	0.970
Lamp Dirt Depreciation Factor	0.840	0.840	0.840	0.840	0.840
Light Loss Factor	0.815	0.815	0.815	0.815	0.815

TABLE 45

EMERGENCY LIGHTING INPUT DATA FOR 40 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER AREA	COOLER AREA	VESTIBULE
Total Length	1,320	1,320	150	150	395
Total Width	330	1,320	75	150	20
Room Cavity Length	110	110	75	75	98.8
Room Cavity Width	110	110	75	75	20
Effective Ceiling Reflectance	73	73	70	70	61
Wall Reflectance	50	50	50	50	50
Floor Reflectance	20	20	20	20	20
Design Illumination Level (FC)	1	1	1	1	1
Lamp Type	250W Quartz	250W Quartz	150W Quartz	150W Quartz	250W Quartz
Initial Lumens Per Lamp	4,850	4,850	2,900	2,900	4,850
Coefficient Of Utilization	0.800	0.741	0.767	0.767	0.472
Lamp Lumen Depreciation Factor	0.970	0.970	0.970	0.970	0.970
Lamp Dirt Depreciation Factor	0.840	0.840	0.840	0.840	0.840
Light Loss Factor	0.815	0.815	0.815	0.815	0.815

TABLE 46

EMERGENCY LIGHTING INPUT DATA FOR 50 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER AREA	COOLER AREA	VESTIBULE
Total Length	1,320	1,320	150	150	395
Total Width	330	1,320	75	150	20
Room Cavity Length	110	110	75	75	98.8
Room Cavity Width	110	110	75	75	20
Effective Ceiling Reflectance	73	73	70	70	61
Wall Reflectance	50	50	50	50	50
Floor Reflectance	20	20	20	20	20
Design Illumination Level	1	1	1	1	1
Lamp Type	250W Quartz	250W Quartz	150W Quartz	150W Quartz	250W Quartz
Initial Lumens Per Lamp	4,850	4,850	2,900	2,900	4,850
Coefficient Of Utilization	0.800	0.692	0.767	0.767	0.472
Lamp Lumen Depreciation Factor	0.970	0.970	0.970	0.970	0.970
Lamp Dirt Depreciation Factor	0.840	0.840	0.840	0.840	0.840
Light Loss Factor	0.815	0.815	0.815	0.815	0.815

TABLE 47

EMERGENCY LIGHTING INPUT DATA FOR 60 FOOT BUILDING

ITEM	OPER AREA	MECH & GEN STOR AREAS	FREEZER AREA	COOLER AREA	VESTIBULE
Total Length	1,320	1,320	150	150	395
Total Width	330	1,320	75	150	20
Room Cavity Length	110	110	75	75	98.8
Room Cavity Width	110	110	75	75	20
Effective Ceiling Reflectance	73	73	70	70	61
Wall Reflectance	50	50	50	50	50
Floor Reflectance	20	20	20	20	20
Design Illumination Level (FC)	1	0.7	1	1	1
Lamp Type	250W Quartz	250W Quartz	150W Quartz	150W Quartz	250W Quartz
Initial Lumens Per Lamp	4,850	4,850	2,900	2,900	4.850
Coefficient Of Utilization	0.800	0.577	0.767	0.767	0.472
Lamp Lumen Depreciation Factor	0.970	0.970	0.970	0.970	0.970
Lamp Dirt Depreciation Factor	0.840	0.840	0.840	0.840	0.840
Light Loss Factor	0.815	0.815	0.815	0.815	0.815

TABLE 48

EMERGENCY LIGHTING COST INPUT DATA

AREA	OPER AREA	MECH & GEN STOR AREAS	FREEZER AREA	COOLER AREA	VESTIBULE
30 Foot Building:					
Emergency Luminaire Option	9.00	9.00	9.00	9.00	9.00
Lamp Cost	6.90	6.90	6.80	6.80	6.90
Circuit Cost	1083.00	811.00	811.00	811.00	811.00
40 Foot Building:					
Emergency Luminaire Option	9.00	9.00	9.00	9.00	9.00
Lamp Cost	6.90	6.90	6.80	6.80	6.90
Circuit Cost	1083.00	911.00	811.00	811.00	811.00
50 Foot Building:					
Emergency Luminaire Option	9.00	9.00	9.00	9.00	9.00
Lamp Cost	6.90	6.90	6.80	6.80	6.90
Circuit Cost	1083.00	1010.00	811.00	811.00	811.00
60 Foot Building:					
Emergency Luminaire Option	9.00	9.00	9.00	9.00	9.00
Lamp Cost	6.90	6.90	6.80	6.80	6.80
Circuit Cost	1083.00	1020.00	811.00	811.00	811.00

TABLE 49

EMERGENCY LIGHTING DESIGN AND COST RESULTS FOR 30 FOOT BUILDING

ITEM	OPER AREA	GEN STORAGE AREA	MECH AREA	FREEZER/ COOLER
Number Of Luminaires	138	414	138	41
Number Of Circuits	17	49	17	6
Luminaire Cost	$ 1,242.00	$ 3,726.00	$ 1,242.00	$ 369.00
Lamp Cost	$ 952.20	$ 2,856.60	$ 952.20	$ 279.10
Circuit Cost	$18,411.00	$39,739.00	$13,787.00	$4,866.00
Total Initial Cost	$20,605.20	$46,321.60	$15,981.20	$5,514.10
System Annual Cost	$ 2,270.07	$ 5,103.25	$ 1,760.65	$ 607.49
System Cost Per 1000 Cu Ft	$ 0.17	$ 0.13	$ 0.13	$ 0.47

TABLE 50

EMERGENCY LIGHTING DESIGN AND COST RESULTS FOR 40 FOOT BUILDING

ITEM	OPER AREA	GEN STORAGE AREA	MECH AREA	FREEZER/ COOLER
Number Of Luminaires	138	447	149	41
Number Of Circuits	17	53	18	6
Luminaire Cost	$ 1,242.00	$ 4,023.00	$ 1,341.00	$ 369.00
Lamp Cost	$ 952.20	$ 3,084.30	$ 1,028.10	$ 279.10
Circuit Cost	$18,411.00	$48,283.00	$16,398.00	$4,866.00
Total Initial Cost	$20,605.20	$55,390.30	$18,767.10	$5,514.10
System Annual Cost	$ 2,270.07	$ 6,102.35	$ 2,067.57	$ 607.49
System Cost Per 1000 Cu Ft	$ 0.17	$ 0.12	$ 0.12	$ 0.47

TABLE 51

EMERGENCY LIGHTING DESIGN AND COST RESULTS FOR 50 FOOT BUILDING

ITEM	OPER AREA	GEN STORAGE AREA	MECH AREA	FREEZER/ COOLER
Number Of Luminaires	138	479	159	41
Number Of Circuits	17	57	19	6
Luminaire Cost	$ 1,242.00	$ 4,311.00	$ 1,431.00	$ 369.00
Lamp Cost	$ 952.20	$ 3,305.10	$ 1,097.10	$ 279.10
Circuit Cost	$18,411.00	$57,570.00	$19,190.00	$4,866.00
Total Initial Cost	$20,605.20	$65,186.10	$21,718.10	$5,514.10
System Annual Cost	$ 2,270.07	$ 7,181.55	$ 2,392.68	$ 607.49
System Cost Per 1000 Cu Ft	$ 0.17	$ 0.11	$ 0.11	$ 0.47

TABLE 52

EMERGENCY LIGHTING DESIGN AND COST RESULTS FOR 60 FOOT BUILDING

ITEM	OPER AREA	GEN STORAGE AREA	MECH AREA	FREEZER/ COOLER
Number Of Luminaires	138	419	140	41
Number Of Circuits	17	50	17	6
Luminaire Cost	$ 1,242.00	$ 3,771.00	$ 1,260.00	$ 369.00
Lamp Cost	$ 952.20	$ 2,891.10	$ 960.00	$ 279.10
Circuit Cost	$18,411.00	$51,000.00	$17,340.00	$4,866.00
Total Initial Cost	$20,605.20	$57,662.10	$19,560.00	$5,514.10
System Annual Cost	$ 2,270.07	$ 6,352.63	$ 2,154.92	$ 607.49
System Cost Per 1000 Cu Ft	$ 0.17	$ 0.08	$ 0.08	$ 0.47

Load Data

For the proper design of an electric power distribution system, a good estimate of the locations, characteristics, and demands of the electric load is required. Since this load data was not readily available, the loads had to be calculated or obtained from information on similar existing facilities. The size of the electrical loads for the 30, 40, 50, and 60 foot warehouses is tabulated in Table 53. This load data was used in the design of the primary power distribution system.

The warehouse was divided into electrical load areas to show the approximate location of each load. These load areas were labeled 1 through 10 as shown in Figure 25. The electrical loads in Table 53 were re-distributed into these load areas as shown in Tables 54 through 57. The load areas were also selected as shown to minimize voltage drops in the low voltage, high current secondary feeders and to minimize cable sizes and lengths. If bigger areas were selected, cable sizes must be increased to minimize voltage drops (Beeman, 1955:622-629). Each area was limited to approximately 2000 kilovoltamperes (KVA) to facilitate electrical equipment selection and to obtain an economical distribution system (Beeman, 1955:664-665).

The kilowatt (KW) loads in Tables 53 through 57 were the maximum, or connected, KW loads in each area. Note that in Tables 53 through 57 the load for the mechanical equipment room and load area 10 may be one of two values. One is the electrical load if commercial power is utilized, and the other is the load if a total energy system is installed to provide power.

The power factor (PF) for the lighting loads was .99 (GE, 1974b:9).

The power factors for the remaining loads were assumed to be .85 (ASHRAE, 1975:34). The demand factors, which are the ratios of the maximum demand of a system to the total connected load of the system (NEC, 1974:70-7), were specified by EATG to be 1.0 for the lighting loads and .75 for all other loads. The diversity factor is the ratio of the sum of the individual maximum demands of the various subdivisions of the system to the maximum demand of the entire system under consideration (Westinghouse, 1965:25). The diversity factor was assumed to be 1.00. The assumed diversity factor is a conservative value commonly used in design studies (Beeman, 1955:888).

The reactive power or kilovar power (KVAR), which is the power required to establish magnetic fields in inductive loads, such as transformers and induction motors, was calculated using Equation (6).

$$KVAR = (KW)(Tan\{Arc\ Cos\ (PF)\}) \quad (6)$$

The total power or apparent power in kilovoltamperes (KVA) was calculated using Equation (7).

$$KVA = \sqrt{(KW)^2 + (KVAR)^2} \quad (7)$$

The demand load or demand KVA, which was used to design the primary distribution system, was calculated using Equation (8).

$$Demand\ KVA = (Demand\ Factor)(KVA)/(Diversity\ Factor) \quad (8)$$

This data is tabulated in Tables 54 through 57.

The loads within each load area were based on the functional requirements of this facility. Lighting loads were determined, as shown in the lighting design section, using recommended illumination requirements for different functional areas of a warehouse. Fan loads, 200 ton chiller load for the mechanical equipment room (area 10) were determined in the mechanical engineering section of this report. Computer and minicomputer

loads, material handling equipment loads, crane and stacker crane loads, and battery charger loads were obtained from EATG.

TABLE 53

ELECTRICAL LOAD DATA IN KILOWATTS

	WAREHOUSE			
	30 FT	40 FT	50 FT	60 FT
Operating Area				
Material Handling	1341			
Computer	72			
Receiving Mini Computer	3			
Packing Mini Computer	1.5			
Shipping Mini Computer	1.5			
Lights	348			
Fans	248			
Total	2015			
Mechanized Area				
Stacker Cranes	3591	2781	2331	1971
Mini Computer	3	3	3	3
Lights	139	150	161	158
Fans	400	357	195	175
Total	4133	3291	2690	2307
General Storage Area				
Cranes	200	200	200	200
Battery Charger	500	637	839	975
Lights	417	450	482	474
Fans	137	182	228	274
Total	1254	1469	1749	1923

TABLE 53 CONTINUED

	WAREHOUSE			
	30 FT	40 FT	50 FT	60 FT
Freezer/Cooler Area				
200 Ton Chiller	390			
Lights	23			
Fans	50			
Total	463			
Mechanical Equipment Room *				
A/C Equipment (Commercial Power)	2200	2133	1967	1867
Or				
Total Energy Equipment	420	380	350	350
Total (Total Energy/Commercial Power)	8285/10065	7618/9371	7267/8884	7058/8575

* If commercial power is used large centrifugal chillers are required for the HVAC system. If a total energy system is used absorption chillers are used for the HVAC system.

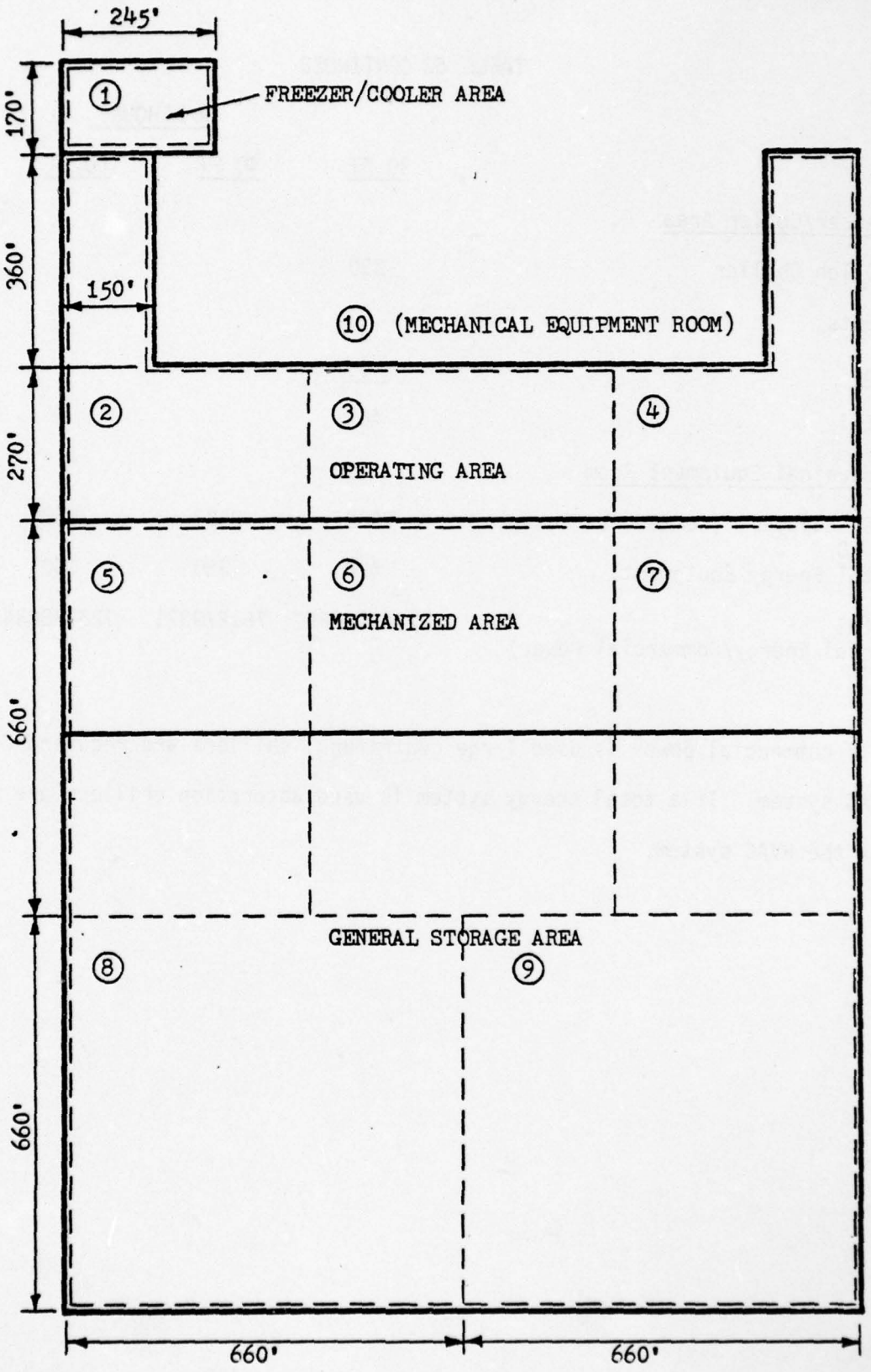


FIGURE 25 ELECTRICAL LOAD AREAS (ENCLOSED IN DASHED LINES)

TABLE 54

ELECTRICAL LOAD DISTRIBUTED IN LOAD AREAS OF 30 FOOT WAREHOUSE

AREA	LOAD	KW	KVAR	KVA	DEMAND KVA
1	Lights	23	3	23	23
	Fans	50	31	59	44
	200 Ton Chiller	390	242	459	344
	Total	463	276	541	411
2	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Mini Computer	3	2	4	3
	Fans	83	51	97	73
	Total	649	347	744	587
3	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Computer	72	45	85	64
	Fans	83	51	97	73
	Total	718	390	825	648
4	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Mini Computer	3	2	4	3
	Fans	83	51	97	73
	Total	649	347	744	587

TABLE 54 CONTINUED

AREA	LOAD	KW	KVAR	KVA	DEMAND KVA
5	Lights	93	13	94	94
	Stacker Cranes	1197	742	1408	1056
	Fans	90	56	106	80
	Mini Computer	3	2	4	3
	Total	1383	813	1612	1233
6	Lights	93	13	94	94
	Stacker Cranes	1197	742	1408	1056
	Fans	90	56	106	80
	Total	1380	811	1608	1230
7	Lights	93	13	94	94
	Stacker Cranes	1197	742	1408	1056
	Fans	90	56	106	80
	Total	1380	811	1608	1230
8	Lights	139	20	140	140
	Cranes	100	62	118	88
	Battery Charger	250	155	294	221
	Fans	134	83	158	118
	Total	623	320	710	567
9	Lights	139	20	140	140
	Cranes	100	62	118	88
	Battery Charger	250	155	294	221
	Fans	134	83	158	118
	Total	623	320	710	567
10	A/C Equipment	2200	1363	2588	1941
	Or				
	TE Equipment	420	260	494	370

TABLE 55

ELECTRICAL LOAD DISTRIBUTED IN LOAD AREAS OF 40 FOOT WAREHOUSE

AREA	LOAD	KW	KVAR	KVA	DEMAND KVA
1	Lights	23	3	23	23
	Fans	50	31	59	44
	200 Ton Chiller	390	242	459	344
	Total	463	276	541	411
2	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Mini Computer	3	2	4	3
	Fans	83	51	97	73
	Total	649	347	744	587
3	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Computer	72	45	85	64
	Fans	83	51	97	73
	Total	718	390	825	648
4	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Mini Computer	3	2	4	3
	Fans	83	51	97	73
	Total	649	347	744	587

TABLE 55 CONTINUED

AREA	LOAD	KW	KVAR	KVA	DEMAND KVA
5	Lights	100	14	101	101
	Stacker Cranes	927	575	1091	818
	Fans	90	56	106	80
	Mini Computer	3	2	4	3
	Total	1120	647	1302	1002
6	Lights	100	14	101	101
	Stacker Cranes	927	575	1091	818
	Fans	90	56	106	80
	Total	1127	645	1298	999
7	Lights	100	14	101	101
	Stacker Cranes	927	575	1091	818
	Fans	90	56	106	80
	Total	1127	645	1298	999
8	Lights	150	21	151	151
	Cranes	100	62	118	88
	Battery Charger	319	198	375	282
	Fans	135	84	159	119
	Total	704	365	803	640
9	Lights	150	21	151	151
	Cranes	100	62	118	88
	Battery Charger	319	198	375	282
	Fans	135	84	159	119
	Total	704	365	803	640
10	A/C Equipment	2133	1322	2509	1882
	Or				
	TE Equipment	380	236	447	335

TABLE 56

ELECTRICAL LOAD DISTRIBUTED IN LOAD AREAS OF 50 FOOT WAREHOUSE

AREA	LOAD	KW	KVAR	KVA	DEMAND KVA
1	Lights	23	3	23	23
	Fans	50	31	59	44
	200 Ton Chiller	390	242	459	344
	Total	463	276	541	411
2	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Mini Computer	3	2	4	3
	Fans	83	51	97	73
	Total	649	347	744	587
3	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Computer	72	45	85	64
	Fans	83	51	97	73
	Total	718	390	825	648
4	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Mini Computer	3	2	4	3
	Fans	83	51	97	73
	Total	649	347	744	587

TABLE 56 CONTINUED

AREA	LOAD	KW	KVAR	KVA	DEMAND KVA
5	Lights	107	15	108	108
	Stacker Cranes	777	482	914	686
	Fans	71	44	84	63
	Mini Computer	3	2	4	3
	Total	958	543	1110	860
6	Lights	107	15	108	108
	Stacker Cranes	777	482	914	686
	Fans	71	44	84	63
	Total	955	541	1106	857
7	Lights	107	15	108	108
	Stacker Cranes	777	482	914	686
	Fans	71	44	84	63
	Total	955	541	1106	857
8	Lights	161	23	163	163
	Cranes	100	62	118	88
	Battery Charger	420	260	494	370
	Fans	105	65	123	93
	Total	786	410	898	714
9	Lights	161	23	163	163
	Cranes	100	62	118	88
	Battery Charger	420	260	494	370
	Fans	105	65	123	93
	Total	786	410	898	714
10	A/C Equipment	1967	1219	2314	1736
	Or				
	TE Equipment	350	217	412	309

TABLE 57

ELECTRICAL LOAD DISTRIBUTED IN LOAD AREAS OF 60 FOOT WAREHOUSE

AREA	LOAD	KW	KVAR	KVA	DEMAND KVA
1	Lights	23	3	23	23
	Fans	50	31	59	44
	200 Ton Chiller	390	242	459	344
	Total	463	276	541	411
2	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Mini Computer	3	2	4	3
	Fans	83	51	97	73
	Total	649	347	744	587
3	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Computer	72	45	85	64
	Fans	83	51	97	73
	Total	718	390	825	648
4	Lights	116	17	117	117
	Mat Handling	447	277	526	394
	Mini Computer	3	2	4	3
	Fans	83	51	97	73
	Total	649	347	744	587

TABLE 57 CONTINUED

AREA	LOAD	KW	KVAR	KVA	DEMAND KVA
5	Lights	105	15	106	106
	Stacker Cranes	657	407	773	580
	Fans	75	46	88	66
	Mini Computer	3	2	4	3
	Total	840	470	971	755
6	Lights	105	15	106	106
	Stacker Cranes	657	407	773	580
	Fans	75	46	88	66
	Total	837	468	967	752
7	Lights	105	15	106	106
	Stacker Cranes	657	407	773	580
	Fans	75	46	88	66
	Total	837	468	967	752
8	Lights	211	30	213	160
	Cranes	100	62	118	88
	Battery Charger	488	302	574	430
	Fans	112	69	132	99
	Total	911	463	1037	777
9	Lights	211	30	213	160
	Cranes	100	62	118	88
	Battery Charger	488	302	574	430
	Fans	112	69	132	99
	Total	911	463	1037	777
10	A/C Equipment	1867	1157	2196	1647
	Or				
	TE Equipment	350	217	412	309

Primary Distribution System

An investigation of different primary electrical power distribution systems was conducted for this facility. The primary electrical power distribution system consists of the circuit between the primary substation to the transformer secondary buses in the unit substations. Modern power distribution systems are designed using the load center concept where power is distributed at high voltages to several unit substations located close to the center of electrical loads. The objective of this concept is to minimize voltage drops in the low voltage, high current secondary feeders and to minimize secondary cable sizes and lengths (Beeman, 1955: 622-625). Each unit substation handles the load in one load area as shown on Figure 25.

The secondary distribution system was not designed since the exact location of the loads within a load area and the load characteristics were not available. The secondary power distribution system consists of the low voltage distribution system between the transformer secondary bus in the unit substation and the electrical energy consuming equipment.

The unit substations in the load center power distribution system can be connected in many circuit arrangements. The selection of the circuit arrangement for this facility depended upon cost, flexibility, service reliability, simplicity, short circuit protection requirements, and maintainability.

Circuit Arrangement. The three types of circuit arrangements investigated were the simple radial, the looped primary, and the primary selective-secondary selective. Variations and combinations of these circuit arrangements are described in many industrial engineering handbooks (IEEE, 1974a: 11-19).

The simplest and most common circuit arrangement is the radial type

shown in Figure 26. It employs one high voltage feeder between the primary substation and the unit substations. Each unit substation consists of one transformer sized to handle the load in the designated load area. It is easy to operate, usually the easiest to protect, and usually the lowest in first cost. However, it is the least reliable, since a fault in the primary feeder or transformer will result in the loss of electrical power to the unit substation and the load area served by it.

The looped primary arrangement shown in Figure 27 offers some advantages where the loads, and thus the unit substations, are relatively far apart. The length of the primary feeders may be reduced by using this arrangement. The looped primary arrangement cost only slightly less than the radial arrangement, but it is difficult to protect. In the event of a fault in a transformer or the primary loop, the entire primary loop must be deenergized, and the process of locating and isolating the fault can be complex and time consuming. If a fault in a unit substation transformer is located and isolated, power can be restored to all unit substations except to that where the fault is located. Power cannot be restored to the load area where the fault occurred until the fault is cleared.

The primary selective-secondary selective arrangement shown on Figure 28 is similar to the radial system except that two primary feeders, two transformers, and a circuit between transformer secondary buses are involved. The two transformers could be the transformers at two substations. However, this requires a long low voltage, extremely high current secondary tie cable between transformers. This method of providing selectivity is not feasible for this facility. However, if two transformers at each unit substation were fed by two separate primary feeders, the long secondary

tie cable between transformers is not required. The transformers normally operate as separate radial systems with the tie switch open. If a fault should occur in a transformer or a primary feeder, the tie switch is closed, and one transformer supplies power to the area. This arrangement increases the service reliability.

The electrical load in one area is normally divided equally between the two transformers in the selective arrangement. EATG requested that the transformers and primary feeders be sized so that either of the transformers in the unit substations is able to carry the entire area load in the event that one of the transformers or primary feeders fails. Under normal operating conditions, there is twice as much capacity as required. This additional transformer capacity, plus the requirement for the additional primary feeder, increases the first cost of the primary selective-secondary selective arrangement over that of a radial system or a looped primary system.

After investigating the reliability of the components of the primary distribution system, the primary selective-secondary selective distribution system was selected for this facility. It met the service reliability requirements desired by EATG. The one line diagram of the circuit arrangement selected for this facility is shown in Figure 29. Only one primary feeder to each unit substation and one transformer at each unit substation is shown. Figure 28 shows the details of this circuit arrangement.

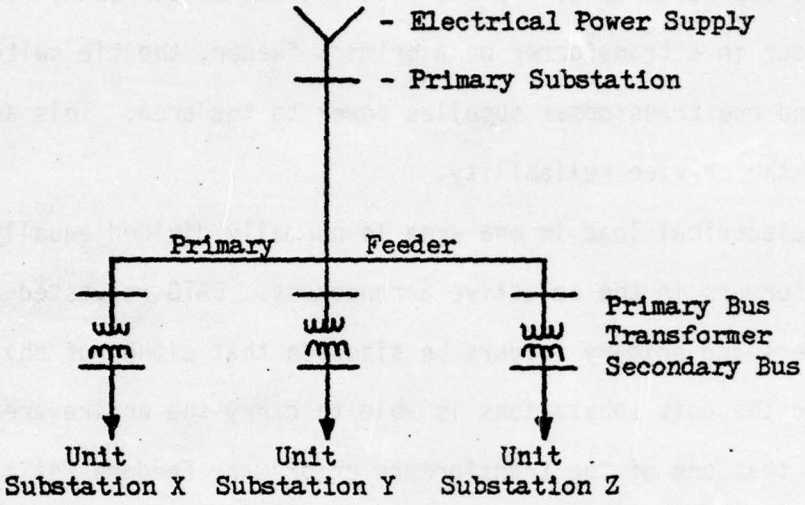


FIGURE 26 RADIAL CIRCUIT ARRANGEMENT

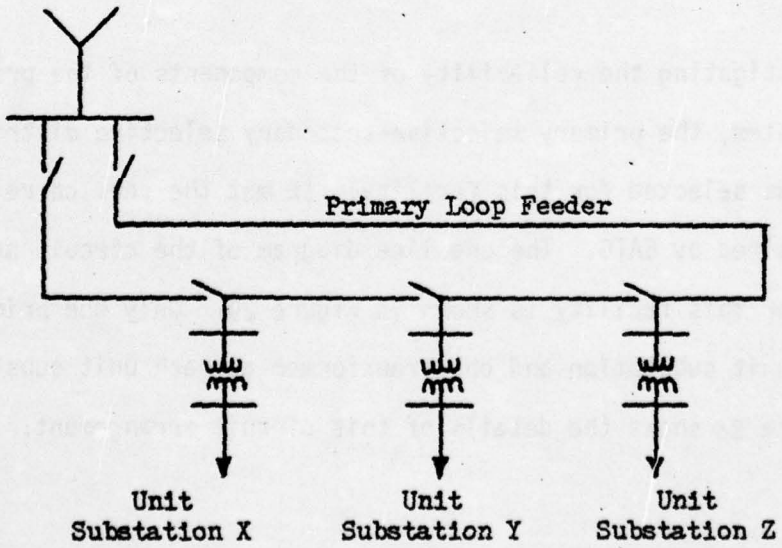
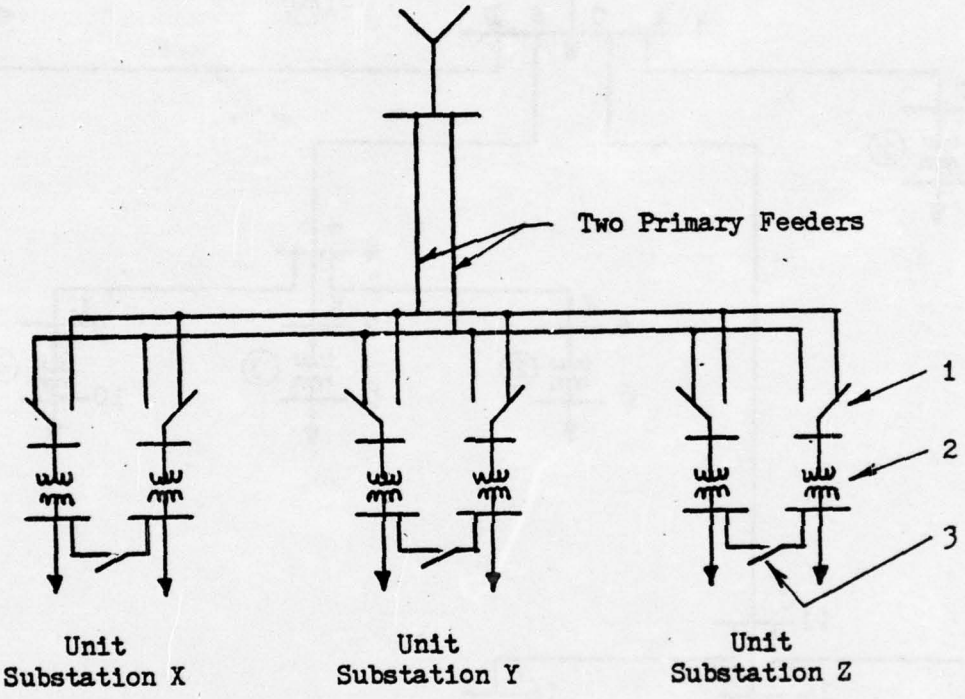


FIGURE 27 LOOPED PRIMARY CIRCUIT ARRANGEMENT

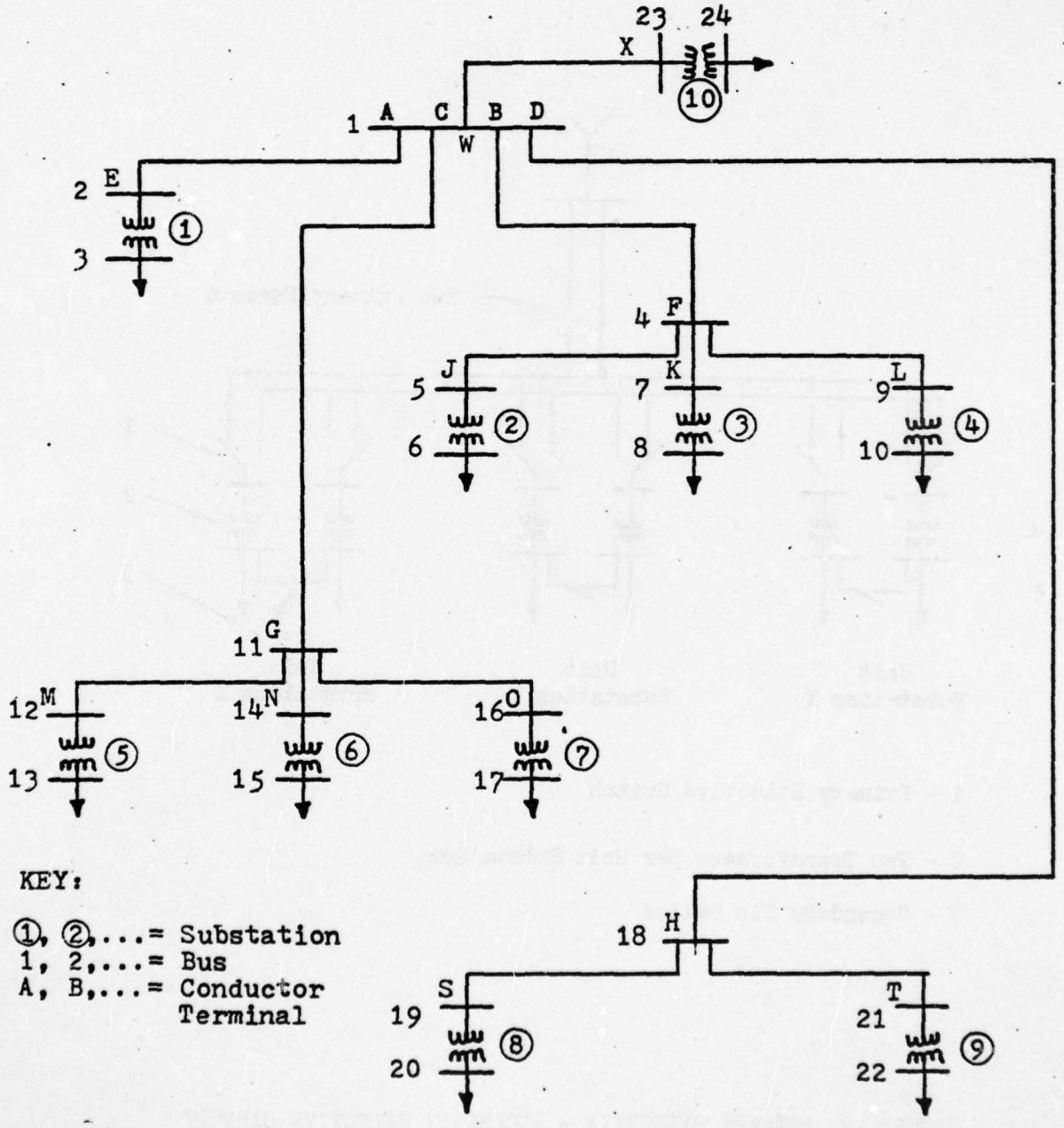


1 - Primary Selective Switch

2 - Two Transformers per Unit Substation

3 - Secondary Tie Switch

FIGURE 28 PRIMARY SELECTIVE - SECONDARY SELECTIVE CIRCUIT ARRANGEMENT



KEY:

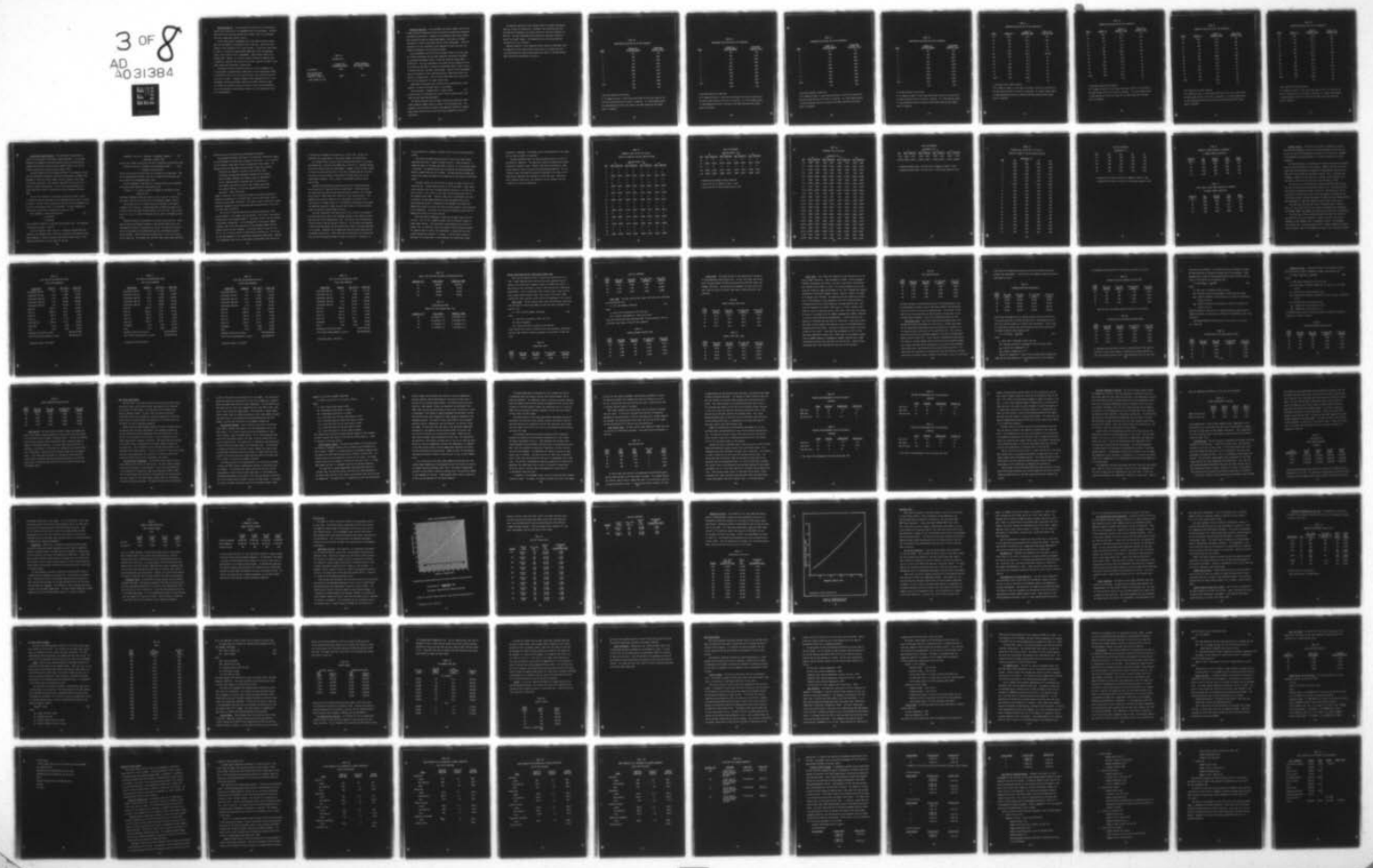
①, ②,...= Substation
1, 2,...= Bus
A, B,...= Conductor Terminal

FIGURE 29 CABLE DIAGRAM FOR ONE PRIMARY FEEDER AND ONE TRANSFORMER TO EACH SUBSTATION

AD-A031 384 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 13/2
A GENERAL WAREHOUSE MODULE CONCEPTUAL DESIGN AND COST ANALYSIS.--ETC(U)
SEP 76 R T ALEXANDER, T J CARMICHAEL

UNCLASSIFIED GCE/MC/76S-1-VOL-2 NL

3 OF 8
AD A031384




OF 8
31384
1.0
1.1
1.25
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1.8
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2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

System Reliability. In evaluating the reliability of a distribution system, the reliability of its components must be investigated. Table 58 shows the failure rate and average time to repair data for transformers and high voltage power cables in ducts.

In the simple radial arrangement and in the looped primary arrangement ten transformers are required for this facility. One of the transformers on the average will fail every 40 years. A fault will occur every 27 years in a section of approximately 6000 feet of high voltage power cables used in these circuit arrangements. These failure rates are extremely good. However, this facility cannot tolerate the complete loss of power to a load area for the 96.8 or 217 hours required to repair faulty power cables and transformers, respectively.

The primary selective-secondary selective circuit arrangement uses 20 transformers and approximately 12000 feet of high voltage power cables. A transformer failure will occur every 20 years, and a cable failure will occur every 14 years. However, because of the redundancy of this circuit arrangement and the transformer capacities provided, electrical power will always be available to each load area as long as both transformers in a unit substation or both primary feeders to a unit substation do not fail simultaneously.

TABLE 58

FAILURE DATA *

	FAILURE RATE (FAILURES/YR-UNIT)	AVERAGE DOWNTIME PER FAILURE (HOURS)
Transformers	.0025	217
High Voltage Cable In Conduit Below Ground (Per 1000 Ft)	.00613	96.8

* IEEE, (1974b:213-235)

Equipment Selection. The transformer and primary feeder sizes for the primary selective-secondary selective distribution system were determined from design calculations. Standard size transformers and primary feeders were selected to meet the design requirements, since they are readily available for initial installation and for future replacement. Tables 59 through 62 list the transformer sizes selected for each load area, and Tables 63 through 66 list the cables selected.

The transformers can be oil-filled, askarel-filled, or the dry type. Oil filled transformers are the least expensive, but must be installed in ventilated transformer vaults if they are installed indoors (NEC, 1974:70-337). Dry type transformers are almost twice as expensive as the oil-filled type and must be located in transformer rooms if their rating is greater than 112.5 KVA (NEC, 1974:70-336). Askarel filled transformers were not considered in this study because their fumes may be toxic and could be a safety hazard. The oil-filled transformers were selected for this facility because of its lower overall cost.

Approximate transformer size for each area was determined by using Equation (9) where the growth factor is 50 percent.

$$\text{KVA transformer} = (\text{Demand KVA})(1 + \text{growth factor}) \qquad (9)$$

A growth factor of 50 percent was used to allow for growth and for any loads that may have been overlooked.

The cables selected for the primary distribution system were three single conductor copper cables in conduit in the concrete floor. The conductor size selection was based on the ampacity required to transmit power safely and efficiently from the primary substation to the unit substations.

The ampacity required for each primary feeder was based on the design capacity at each unit substation. Although a unit substation may have two 1000 KVA transformers, the design capacity of that unit substation is 1000 KVA. The two transformers were installed to increase reliability and not for growth reasons. The conductors were sized using Equation (10) where KV = 13.2 kilovolts.

Ampacity Required = (Unit Substation Design Capacity, KVA)/$\sqrt{3}$(KV) (10)

The ampacities of the cables selected were equal to a greater than the calculated ampacities required and greater than that of a #8 AWG conductor (NEC, 1974:70-143 and AFM 88-15, 1975:8-3).

TABLE 59

TRANSFORMER SELECTION FOR 30 FOOT WAREHOUSE

AREA	DEMAND KVA WITH 50% GROWTH	TRANSFORMER SELECTED, KVA *
1	617	750
2	881	1000
3	972	1000
4	881	1000
5	1850	2000
6	1845	2000
7	1845	2000
8	851	1000
9	851	1000
10**	2912	2500
	555	500

* Two each required in each area.

** If commercial power is used large centrifugal chillers are required for the HVAC system and the first entry is required. If a total energy system is used absorption chillers are used for the HVAC system and the second entry is required.

TABLE 60

TRANSFORMER SELECTION FOR 40 FOOT WAREHOUSE

AREA	DEMAND KVA WITH 50% GROWTH	TRANSFORMER SELECTED, KVA *
1	617	750
2	881	1000
3	972	1000
4	881	1000
5	1503	1500
6	1499	1500
7	1499	1500
8	960	1000
9	960	1000
10**	2823	2500
	503	500

* Two each required in each area.

** If commercial power is used large centrifugal chillers are required for the HVAC system and the first entry is required. If a total energy system is used absorption chillers are used for the HVAC system and the second entry is required.

TABLE 61

TRANSFORMER SELECTION FOR 50 FOOT WAREHOUSE

AREA	DEMAND KVA WITH 50% GROWTH	TRANSFORMER SELECTED, KVA *
1	617	750
2	881	1000
3	972	1000
4	881	1000
5	1290	1500
6	1286	1500
7	1286	1500
8	1071	1000
9	1071	1000
10**	2604	2500
	464	500

* Two each required in each area.

** If commercial power is used large centrifugal chillers are required for the HVAC system and the first entry is required. If a total energy system is used absorption chillers are used for the HVAC system and the second entry is required.

TABLE 62

TRANSFORMER SELECTION FOR 60 FOOT WAREHOUSE

AREA	DEMAND KVA WITH 50% GROWTH	TRANSFORMER SELECTED, KVA *
1	617	750
2	881	1000
3	972	1000
4	881	1000
5	1133	1500
6	1128	1500
7	1128	1500
8	1166	1500
9	1166	1500
10**	2471	2500
	464	500

* Two each required in each area.

** If commercial power is used large centrifugal chillers are required for the HVAC system and the first entry is required. If a total energy system is used absorption chillers are used for the HVAC system and the second entry is required.

TABLE 63

CONDUCTOR SELECTION FOR 30 FOOT WAREHOUSE *

CABLE	LENGTH, FT	AMPACITY REQUIRED, AMPS	CABLE SIZE SELECTED, AWG
AE	1030	32.8	#6
BF	125	131.2	#1/0
FJ	440	43.7	#6
FK	10	43.7	#6
FL	440	43.7	#6
CG	580	262.4	300 MCM
GM	440	87.5	#3
GN	10	87.5	#3
GO	440	87.5	#3
DH	1240	87.5	#3
HS	330	43.7	#6
HT	330	43.7	#6
WX**	300	109.3	#2
		21.9	#6

* See Figure 29 for cable location.

** If commercial power is used large centrifugal chillers are required for the HVAC system and the first entry is required. If a total energy system is used absorption chillers are used for the HVAC system and the second entry is required.

TABLE 64

CONDUCTOR SELECTION FOR 40 FOOT WAREHOUSE *

CABLE	LENGTH, FT	AMPACITY REQUIRED, AMPS	CABLE SIZE SELECTED, AWG
AE	1030	32.8	#6
BF	125	131.2	#1/0
FJ	440	43.7	#6
FK	10	43.7	#6
FL	440	43.7	#6
CG	580	196.8	#3/0
GM	440	65.6	#6
GN	10	65.6	#6
GO	440	65.6	#6
DH	1240	87.5	#3
HS	330	43.7	#6
HT	330	43.7	#6
WX**	300	109.3	#2
		21.9	#6

* See Figure 29 for cable location.

** If commercial power is used large centrifugal chillers are required for the HVAC system and the first entry is required. If a total energy system is used absorption chillers are used for the HVAC system and the second entry is required.

TABLE 65

CONDUCTOR SELECTION FOR 50 FOOT WAREHOUSE *

CABLE	LENGTH, FT	AMPACITY REQUIRED, AMPS	CABLE SIZE SELECTED, AWG
AE	1030	32.8	#6
BF	125	131.2	#1/0
FJ	440	43.7	#6
FK	10	43.7	#6
FL	440	43.7	#6
CG	580	196.8	#3/0
GM	440	65.6	#6
GN	10	65.6	#6
GO	440	65.6	#6
DH	1240	87.5	#3
HS	330	43.7	#6
HT	330	43.7	#6
WX**	300	109.3	#2
		21.9	#6

* See Figure 29 for cable location.

** If commercial power is used large centrifugal chillers are required for the HVAC system and the first entry is required. If a total energy system is used absorption chillers are used for the HVAC system and the second entry is required.

TABLE 66

CONDUCTOR SELECTION FOR 60 FOOT WAREHOUSE *

CABLE	LENGTH, FT	AMPACITY REQUIRED, AMPS	CABLE SIZE SELECTED, AWG
AE	1030	32.8	#6
BF	125	131.2	#1/0
FJ	440	43.7	#6
FK	10	43.7	#6
FL	440	43.7	#6
CG	580	196.8	#3/0
GM	440	65.6	#6
GN	10	65.6	#6
GO	440	65.6	#6
DH	1240	131.2	#1/0
HS	330	65.6	#6
HT	330	65.6	#6
WX**	300	109.3	#2
		21.9	#6

* See Figure 29 for cable location.

** If commercial power is used large centrifugal chillers are required for the HVAC system and the first entry is required. If a total energy system is used absorption chillers are used for the HVAC system and the second entry is required.

Distribution System Analysis. The distribution system shown in Figure 29 was analyzed using computer program LOAD-FLOW. This program determines the adequacy of the distribution system by calculating the voltage drops and the real and reactive powers at each bus of the distribution system by an iterative process (Heer, 1975).

The data required for this program consisted of the conductor resistance and reactance, transformer resistance and reactance, estimated loads expressed in real and reactive powers, and the voltage at the primary distribution substation. This data was converted to the per unit (p.u.) system to simplify calculations. The per unit system normalizes the actual electrical values to selected base values (Stevenson, 1975:121-148).

The one line diagram for the primary distribution system is shown in Figure 29, and the connected load and impedance data are given in Tables 67 and 68. The base values selected were 100 MVA (million voltampere) and 13.2 KV on the primary side of the transformer. The base impedance on the primary side was then calculated using Equation (11).

$$\text{Base impedance} = (\text{Base KV})^2/(\text{Base MVA}) \qquad (11)$$

$$= (13.2)^2/100$$

$$= 1.7424 \text{ ohms}$$

The load data in Table 67 is obtained using Equation (12). The connected load values are given in Table 53.

Real (or reactive) load in per unit = Connected load/Base MVA (12)

Similarly, the impedance data in Table 68 is obtained using Equation (13). Cable impedance in ohms was obtained from Electric Power Systems I Compendium by Brockhurst, no data, pages 157 and 162.

Impedance in per unit = Impedance in ohms/Base impedance (13)

= Impedance in ohms/1.7424

Finally, the voltage at any bus in per unit is obtained using Equation (14).

Voltage in per unit = Voltage in kilovolts/Base voltage (14)

= Voltage in kilovolts/13.2

The per unit values do not have any units assigned to its magnitude. They can be converted back to ohms, volts, KW, or KVAR by multiplying the per unit value by the corresponding base value.

Per unit impedance values given at a different base can be converted to the base values desired by using Equation (15).

$$Z\ (new)\ p.u. = Z\ (old)\ p.u.(Base\ KV\ old/Base\ KV\ new)^2(Base\ KVA\ new/Base\ KVA\ old) \quad (15)$$

Transformer impedance values are normally given in per unit values at a given base kilovolts and a given base kilovoltamperes (Beeman, 1955:97).

The voltage at bus 1 in Figure 29 was held constant at the supply voltage of 13.2 kilovolts. Program LOAD-FLOW calculates the power at bus 1, which is the total power being provided to this facility. Zero load at bus 2, 5, 6, etc. in Table 67 indicates that no load is terminated at those buses.

LOAD-FLOW analysis was performed on the worst case conditions. Worst case for the four different buildings is the condition where one of the transformers at each unit substation has failed. The electrical loads at each unit substation are the connected load with the 50 percent growth factor included. Table 69 shows the voltage level, in per unit, at each bus of Figure 29. The voltage level would be higher under normal operating

conditions since the currents and voltage drops are smaller.

The voltage drop between two buses in an electrical distribution system is the difference in voltage levels between the two buses. It is a function of the conductor length and size and the magnitude of the current. The National Electrical Code (NEC) Article 215.2(C) states the following:

> "Conductors for feeders as defined in Article 100, sized to prevent a voltage drop exceeding 3 percent at the farthest outlet of power, heating, and lighting loads, or combinations of such loads and where the maximum total voltage drop on both feeders and branch circuits to the farthest outlet does not exceed 5 percent, will provide reasonable efficiency of operation." (NEC, 1974:70-38)

Feeders include all circuit conductors between the primary substation or generator switchboard of an isolated plant, and the final branch circuit overcurrent device (NEC, 1974:70-8). The branch circuit includes the circuit conductors between the final overcurrent device protecting the circuit and the outlet (NEC, 1974:70-5).

The results in Table 69 show that the maximum voltage drop in the primary feeders is not greater than one percent. This allows a two percent voltage drop in the secondary feeders. The branch circuits are also allowed a two percent voltage drop. As the voltage drop in the primary feeders increases, the size of the conductors for the secondary feeders and the branch circuits must be increased. The voltage levels at buses 3, 6, 8, 10, 13, 15, 17, 20, 22, and 24 in Table 69 are relatively low. This is due to the high impedance of the transformers connected to those buses. However, the transformers being used are tap changing transformers which can be set

to increase the voltage by five percent, or in this case, .05 per unit. Therefore, the voltage drops in the primary feeders are satisfactory.

The voltage levels at buses 4 and 23 indicate that there is no voltage drop between bus 1 and bus 4 and between bus 1 and bus 23. Therefore smaller cable sizes could be used for these feeders. However, since the cable length is relatively short and the price of the cables selected does not vary much from that of the next smaller sized cables, the total cable cost is not significantly affected. This is shown in the economic analysis section that follows.

Normally the distribution system should also be analyzed during the starting periods of large alternating current motors. Starting currents for synchronous and squirrel-cage induction motors started at full voltage, may be seven or eight times their normal full load running current. This momentary high current, especially for large motors, may result in excessive drop in voltage, unless it is considered in the design of the system. The momentary excessive voltage drop may cause lights to flicker and other loads to drop due to undervoltage conditions.

The only large motors that would exist in this facility are assumed to be those required for the chiller equipment located in the mechanical equipment room and in the freezer/cooler area. The chiller units selected have starting current limiting resistors installed. The resistors are connected in series with the motors and are shorted out by steps as the motor approaches full speed. Therefore, the voltage drops during starting conditions can be reduced significantly. These loads are also serviced by unit substations that are fed from separate feeders as shown in Figure 29. Therefore, its

starting effects are somewhat isolated from the rest of the distribution system.

The electrical power being provided to this facility under normal operating conditions is shown in Tables 70 and 71. Table 70 applies if commercial power is utilized, and Table 71 applies if a total energy system is installed. The demand factors were included in the load determination. However, growth factor was not included. The power provided includes the load and the energy dissipated in the conductors of the primary distribution system.

The power factors for this facility as shown in Tables 70 and 71 are relatively low. A power factor as high as .95 is desirable. Power factor may be defined as the ratio of power-producing current in a circuit to the total current in the circuit, or the ratio of the working power (KW) to the apparent power (KVA). Inductive loads such as transformers and induction motors use both power-producing current and magnetizing current. Power-producing current is converted by the equipment into useful work. Magnetizing current is used by the load to produce magnetic fields necessary for its operation. The vector sum of the power-producing current and the magnetizing current is the total current.

There are several advantages to improving the power factor for this facility. First of all, commercial power costs are normally reduced at higher power factors. The distribution system capacity can also be released. That is, additional load can be added to the distribution system. The apparent power or load on the transformer is reduced and the total current through the conductors is reduced. Since the total current is decreased, the voltage drops in the conductors are reduced and voltage

regulation is improved. The reduced current also decreases the real power lost as heat dissipated in conductors.

The most economical means for improving power factors is by the installation of capacitors. The capacitors provide the magnetizing current required for inductive loads. However, they must be installed as close to the inductive loads as possible to achieve maximum benefits. For big inductive loads, the capacitors should be connected to the load, so the load and the capacitors are switched on at the same time. Where many small inductive loads exist, the capacitors can be located at the low voltage bus in the unit substations.

TABLE 67

CONNECTED LOAD IN PER UNIT VALUES

(REFER TO FIGURE 29 FOR BUS IDENTIFICATION)

	BUILDING HEIGHT (FT)							
	30		40		50		60	
BUS	REAL	REACTIVE	REAL	REACTIVE	REAL	REACTIVE	REAL	REACTIVE
1	*	*	*	*	*	*	*	*
2	0	0	0	0	0	0	0	0
3	.00463	.00276	.00463	.00276	.00463	.00276	.00463	.00276
4	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0
6	.00649	.00347	.00649	.00347	.00649	.00347	.00649	.00347
7	0	0	0	0	0	0	0	0
8	.00718	.00390	.00718	.00390	.00718	.00390	.00718	.00390
9	0	0	0	0	0	0	0	0
10	.00649	.00347	.00649	.00347	.00649	.00347	.00649	.00347
11	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0
13	.01383	.00813	.01120	.00647	.00958	.00543	.00840	.00470
14	0	0	0	0	0	0	0	0
15	.01380	.00811	.01127	.00645	.00955	.00541	.00837	.00468
16	0	0	0	0	0	0	0	0
17	.01380	.00811	.01127	.00645	.00955	.00541	.00837	.00468
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	.00623	.00320	.00704	.00365	.00786	.00410	.00911	.00463

TABLE 67 CONTINUED

	BUILDING HEIGHT (FT)							
	30		40		50		60	
BUS	REAL	REACTIVE	REAL	REACTIVE	REAL	REACTIVE	REAL	REACTIVE
21	0	0	0	0	0	0	0	0
22	.00623	.00320	.00704	.00365	.00786	.00410	.00911	.00463
23	0	0	0	0	0	0	0	0
24+	.02200	.01363	.02133	.01322	.01967	.01219	.01867	.01157
24Δ	.00420	.00260	.00380	.00236	.00350	.00217	.00350	.00217

* Determined By Computer Program LOAD-FLOW

+ Load At Bus 24 If Commercial Power Is Used

Δ Load At Bus 24 If Total Energy System Is Used

TABLE 68

IMPEDANCE DATA IN PER UNIT

	WAREHOUSE (FT)							
	30		40		50		60	
BUS	REAL	REACTIVE	REAL	REACTIVE	REAL	REACTIVE	REAL	REACTIVE
1-2	.2699	.0367	.2699	.0367	.2699	.0367	.2699	.0367
2-3	1.3330	7.3330	1.3330	7.3330	1.3330	7.3330	1.3330	7.3330
1-4	.0083	.0033	.0083	.0033	.0083	.0033	.0083	.0033
4-5	.1152	.0157	.1152	.0157	.1152	.0157	.1152	.0157
5-6	1.0000	5.5000	1.0000	5.5000	1.0000	5.5000	1.0000	5.5000
4-7	.0026	.0004	.0026	.0004	.0026	.0004	.0026	.0004
7-8	1.0000	5.5000	1.0000	5.5000	1.0000	5.5000	1.0000	5.0000
4-9	.1152	.0157	.1152	.0157	.1152	.0157	.1152	.0157
9-10	1.0000	5.5000	1.0000	5.5000	1.0000	5.5000	1.0000	5.5000
1-11	.0135	.0107	.0241	.0129	.0241	.0129	.0241	.0129
11-12	.0581	.0138	.1152	.0157	.1152	.0157	.1152	.0157
12-13	.5000	2.7500	.6670	3.6670	.6670	3.6670	.6670	3.6670
11-14	.0013	.0013	.0026	.0004	.0026	.0004	.0026	.0004
14-15	.5000	2.7500	.6670	3.6670	.6670	3.6670	.6670	3.6670
11-16	.0581	.0138	.1152	.0157	.1152	.0157	.1152	.0157
16-17	.5000	2.7500	.6670	3.6670	.6670	3.6670	.6670	3.6670
1-18	.1639	.0388	.1639	.0388	.1639	.0388	.0818	.0332
18-19	.0864	.0118	.0864	.0118	.0864	.0118	.0864	.0118
19-20	1.0000	5.5000	1.0000	5.5000	1.0000	5.5000	.6670	3.6670
18-21	.0864	.0118	.0864	.0118	.0864	.0118	.0864	.0118
21-22	1.0000	5.5000	1.0000	5.5000	1.0000	5.5000	.6670	3.6670
1-23*	.0314	.0089	.0314	.0089	.0314	.0089	.0314	.0089
23-24*	.4000	2.2000	.4000	2.2000	.4000	2.2000	.4000	2.2000

TABLE 68 CONTINUED

	WAREHOUSE (FT)							
	30		40		50		60	
BUS	REAL	REACTIVE	REAL	REACTIVE	REAL	REACTIVE	REAL	REACTIVE
1-23+	.0786	.0107	.0786	.0107	.0786	.0107	.0786	.0107
23-24+	2.0000	10.0000	2.0000	10.0000	2.0000	10.0000	2.0000	10.0000

* Impedance Between Buses 1-23 And 23-24 If Commercial Power Is Used

+ Impedance Between Buses 1-23 And 23-24 If Total Energy System Is Used

TABLE 69

VOLTAGE LEVEL IN PER UNIT AT EACH BUS

(REFER TO FIGURE 29 FOR BUS IDENTIFICATION)

BUS	WAREHOUSE (FT) 30	40	50	60
1	1.000	1.000	1.000	1.000
2	.998	.998	.998	.998
3	.955	.955	.955	.955
4	1.000	1.000	1.000	1.000
5	.998	.998	.998	.998
6	.957	.957	.957	.957
7	1.000	1.000	1.000	1.000
8	.953	.953	.953	.953
9	.998	.998	.998	.998
10	.957	.957	.957	.957
11	.999	.998	.999	.999
12	.997	.996	.997	.997
13	.950	.945	.954	.961
14	.999	.998	.999	.999
15	.951	.947	.956	.962
16	.997	.996	.997	.997
17	.950	.945	.954	.961
18	.997	.996	.996	.997
19	.996	.995	.994	.996
20	.957	.951	.944	.959
21	.996	.995	.994	.996

TABLE 69 CONTINUED

WAREHOUSE (FT)

BUS	30	40	50	60
22	.957	.951	.944	.959
23*	.999	.999	.999	.999
24*	.934	.936	.942	.945
23+	.999	1.000	1.000	1.000
24+	.943	.949	.953	.953

* Voltage Level At Buses 23 And 24 If Commercial Power Is Used

+ Voltage Level At Buses 23 And 24 If Total Energy System Is Used

TABLE 70

COMMERCIAL POWER PROVIDED TO WAREHOUSE

AT NORMAL DEMAND CONDITIONS

WAREHOUSE (FT)	REAL (KW)	REACTIVE (KVAR)	TOTAL (KVA)	POWER FACTOR
30	7807	4546	9036	.864
40	7312	4206	8436	.867
50	6938	3948	7982	.869
60	6808	3798	7796	.873

TABLE 71

TOTAL ENERGY SYSTEM POWER PROVIDED TO WAREHOUSE

AT NORMAL DEMAND CONDITIONS

WAREHOUSE (FT)	REAL (KW)	REACTIVE (KVAR)	TOTAL (KVA)	POWER FACTOR
30	6690	3688	7638	.876
40	6224	3360	7074	.880
50	5940	3170	6732	.882
60	5850	3068	6606	.886

Economic Analysis. The initial fixed capital investment on the primary selective-secondary selective distribution systems are shown for the 30, 40, 50, and 60 foot warehouses on Tables 72, 73, 74, and 75. Standard size equipment was selected because it is readily available and is more economical.

As indicated earlier, the secondary distribution system was not designed since the load characteristics were unknown. However, the cost of the secondary distribution system was assumed to be approximately one-third of the total cost of the electrical distribution system. This is a typical cost breakdown. However, the cost really is a function of the location, characteristics, and size of the individual loads (Brockhurst, 1976).

The first cost of the distribution system was amortized over 25 years with zero salvage value and ten percent interest rate. The annual cost for the different warehouses are shown on Table 76. Maintenance cost was not included in the annual cost, since little maintenance is required for the distribution system. Maintenance normally includes dusting, cleaning contacts, and transformer oil level and composition checks once or twice a year.

The annual cost per 1000 cubic feet of warehouse space is shown on Table 77. The volume of 30, 40, 50, and 60 foot warehouse was determined to be 66204, 83892, and 101580, and 119268 thousand cubic feet, respectively.

The first cost of the distribution system is primarily a function of the electrical load of the warehouse. However, the total cost is also dependent on the standard sizes of equipment available. The equipment was selected with a 50 percent growth factor. However, because of standard sizes available, some of the equipment can handle a 60 or 70 percent growth.

TABLE 72

COST DATA FOR DISTRIBUTION SYSTEM

FOR 30 FOOT WAREHOUSE

DESCRIPTION	QUANTITY	UNIT COST *	TOTAL COST
Transformer 500 KVA	2 Ea	$ 5,565	$ 11,130
Transformer 750 KVA	2 Ea	9,825	19,650
Transformer 1000 KVA	10 Ea	12,675	126,750
Transformer 2000 KVA	6 Ea	21,000	126,000
Transformer 2500 KVA	2 Ea	25,750	51,500
Cable #6	5760 Ft	14.41	83,002
Cable #3	4260 Ft	15.46	65,860
Cable #2	600 Ft	16.03	9,618
Cable 1/0	250 Ft	17.79	4,448
Cable 300 MCM	1160 Ft	32.76	38,002
Switchgear	20 Ea	4,000	80,000
Vault	10 Ea	2,500	25,000
Secondary Distribution System			289,921/310,592
Total (Total Energy/Commercial Power)			869,763/931,776

* Reference (Means, 1974,1975)

TABLE 73

COST DATA FOR DISTRIBTUION SYSTEM

FOR 40 FOOT WAREHOUSE

DESCRIPTION	QUANTITY	UNIT COST *	TOTAL COST
Transformer 500 KVA	2 Ea	$ 5,565	$ 11,130
Transformer 750 KVA	2 Ea	9,825	19,650
Transformer 1000 KVA	10 Ea	12,675	126,750
Transformer 1500 KVA	6 Ea	16,530	99,180
Transformer 2500 KVA	2 Ea	25,750	51,500
Cable #6	7540 Ft	14.41	108,651
Cable #3	2480 Ft	15.46	38,341
Cable #2	600 Ft	16.03	9,618
Cable 1/0	250 Ft	17.79	4,448
Cable 3/0	1160 Ft	20.27	23,513
Switchgear	20 Ea	4,000	80,000
Vault	10 Ea	2,500	25,000
Secondary Distribution System			268,332/289,003
Total (Total Energy/Commercial Power)			804,995/967,008

* Reference (Means 1974,1975)

TABLE 74

COST DATA FOR DISTRIBUTION SYSTEM

FOR 50 FOOT WAREHOUSE

DESCRIPTION	QUANTITY	UNIT COST *	TOTAL COST
Transformer 500 KVA	2 Ea	$ 5,565	$ 11,130
Transformer 750 KVA	2 Ea	9,825	19,650
Transformer 1000 KVA	10 Ea	12,675	126,750
Transformer 1500 KVA	6 Ea	16,530	99,180
Transformer 2500 KVA	2 Ea	25,750	51,500
Cable #6	7540 Ft	14.41	108,651
Cable #3	2480 Ft	15.46	38,341
Cable #2	600 Ft	16.03	9,618
Cable 1/0	250 Ft	17.79	4,448
Cable 3/0	1160 Ft	20.27	23,513
Switchgear	20 Ea	4,000	80,000
Vault	10 Ea	2,500	25,000
Secondary Distribution System			268,332/289,003
Total (Total Energy/Commercial Power)			804,995/867,008

* Reference (Means, 1974,1975)

TABLE 75

COST DATA FOR DISTRIBUTION SYSTEM

FOR 60 FOOT WAREHOUSE

DESCRIPTION	QUANTITY	UNIT COST *	TOTAL COST
Transformer 500 KVA	2 Ea	$ 5,565	$ 11,130
Transformer 750 KVA	2 Ea	9,825	19,650
Transformer 1000 KVA	6 Ea	12,675	76,050
Transformer 1500 KVA	10 Ea	16,530	165,300
Transformer 2500 KVA	2 Ea	25,750	51,500
Cable #6	7540 Ft	14.41	108,651
Cable # 2	600 Ft	16.03	9,618
Cable 1/0	2730 Ft	17.79	48,567
Cable 3/0	1160 Ft	20.27	23,513
Switchgear	20 Ea	4,000	80,000
Vault	10 Ea	2,500	25,000
Secondary Distribution System			278,931/299,602
Total (Total Energy/Commercial Power)			836,792/898,805

* Reference (Means, 1974,1975)

TABLE 76

ANNUAL COST DATA FOR ELECTRICAL DISTRIBUTION SYSTEM

WAREHOUSE (FT)	TOTAL ENERGY	COMMERCIAL POWER
30	$95,822	$102,654
40	88,686	95,518
50	88,686	95,518
60	92,189	99,021

TABLE 77

DISTRIBUTION SYSTEM

ANNUAL COST PER THOUSAND CUBIC FEET

WAREHOUSE (FT)	TOTAL ENERGY	COMMERCIAL POWER
30	$1.45/1000 Cu Ft	$1.55/1000 Cu Ft
40	$1.06/1000 Cu Ft	$1.14/1000 Cu Ft
50	$ .87/1000 Cu Ft	$ .94/1000 Cu Ft
60	$ .77/1000 Cu Ft	$ .83/1000 Cu Ft

Heating Ventilating and Air Conditioning (HVAC) Loads

HVAC load contributions from six sources were considered for this study. These loads and their daily profiles were analyzed using the American Gas Association's computer simulation, ECUBE75 (AGA, 1975). A description of this simulation is given in the next section, "HVAC Energy Requirements". The six load areas, motor sensible loads, light sensible loads, people sensible/latent loads, solar loads, infiltration loads, transmission loads, and their daily profiles are developed in this section.

Motor Loads. The peak sensible heat loads from the motors associated with the material handling equipment for each zone were calculated using Equation (16).

$$Q = 2.545 \times HP/EFF \quad \text{(ASHRAE, 1972a:420)} \qquad (16)$$

where:

Q = Heat load in thousands of BTU's per hour

HP = Motor horsepower

EFF = Motor efficiency (assumed to be 85 percent)

Table 78 shows the results of converting the zone horsepower requirements outlined under "Material Handling Equipment and Personnel" to peak heat loads.

TABLE 78

MOTOR HEAT LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	4,735	11,947	2,096	18,778

TABLE 78 CONTINUED

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
40	4,735	9,252	2,506	16,493
50	4,735	7,755	3,111	15,601
60	4,735	6,557	3,158	14,450

Light Loads. The peak sensible heat loads from lights were calculated by using Equation (17).

$$Q = 3.4 \times KW \quad \text{(ASHRAE, 1972a:417)} \qquad (17)$$

where:

Q = Heat load in thousands of BTU's per hour

KW = Kilowatt requirement for lights and ballast

Using the lighting KW values developed under "Lighting Design", the sensible heat loads shown in Table 79 were computed.

TABLE 79

LIGHTING SENSIBLE HEATING LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	1,182	472	1,417	3,071
40	1,182	510	1,530	3,222
50	1,182	546	1,639	3,367
60	1,182	537	1,489	3,208

People Loads. The people working in the warehouse were assumed to be doing moderately heavy factory work. At this work rate, each person gives off approximately 375 BTUH sensible heat and 625 BTUH latent heat (ASHRAE, 1972a:416). By multiplying the manpower for each zone by the heat loads per person the design loads shown by Tables 80 and 81 were developed.

TABLE 80

PEOPLE SENSIBLE HEAT LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	527.3	108.0	118.9	754.2
40	527.3	79.9	151.5	758.7
50	527.3	65.6	199.5	792.4
60	527.3	54.0	231.8	813.1

TABLE 81

PEOPLE LATENT HEAT LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	878.8	180.0	198.1	1,256.9
40	878.8	133.1	252.5	1,264.4
50	878.8	109.4	332.5	1,320.7
60	878.8	90.0	386.3	1,355.1

Solar Loads. Solar loads were computed for each daylight hour of the year by ECUBE simulation. Input parameters included: building geometry, latitude, orientation, wall color, roof color, cloud cover, and building heat transfer coefficients (U value). The building geometry used for the study was inputed as shown and developed in the "Civil Engineering" chapter, "Evaluation of Structural Systems" section. Norfolk, Virginia is located at 37 degrees north latitude. The operating area was located on the north face of the warehouse to take advantage of the roof shading provided by the mechanized area as ceiling height was increased above 30 feet. Wall color was assumed to be "light", which gives it a solar radiation color modifier value of 50 percent (Carrier, 1972:1-64). Roof color was assumed to be gray in accordance with the ASHRAE recommendation (ASHRAE, 1972a:412) to allow for smoke and weathering degradation. A solar radiation color modifier of 78 percent was used (Carrier, 1972:1-64). Cloud cover factors were taken from the weather data supplied as part of the ECUBE program by the American Gas Association. Building U values are discussed in the next section of this report. Using these input parameters as well as total equivalent temperature differentials (TETD) input to the computer program from the ASHRAE Handbook of Fundamentals (ASHRAE, 1972a:412-414), ECUBE calculated the hourly solar heat gains for the facility. Table 82 shows the maximum heat loads calculated for each area of the building.

TABLE 82

PEAK SOLAR HEAT GAIN

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	1,765	1,846	5,250	8,861
40	1,758	1,848	5,259	8,865
50	1,750	1,855	5,268	8,873
60	1,742	1,857	5,277	8,876

The small decrease in the peak heat load for the operating area as the building height increases is due to the shade created by the mechanized area as this area rises above the operating area. The increase in heat load for both the mechanized area and the general storage area, as the building height increases, is due to the increased outside wall area.

Ventilation Loads. Ventilation loads were calculated based on the minimum ventilation requirements for the facility. Minimum ventilation for the operating and mechanized areas was specified at one-tenth of an air change per hour during the facility operating hours. This value was derived from ventilation standards suggested in the Carrier System Design Manual (Carrier, 1972:1-97). It was used as a representative value due to the nature of a design concept study in which the actual warehouse product mix, process load ventilation requirements, such as shrink wrap equipment, and building door sizes/locations have not been directly specified. Ten percent per hour represents a relatively high value and provides sufficient ventilation to maintain comfort standards for personnel, as well as sufficient

ventilation for limited truck operations within the building and normal process load requirements. Table 83 lists the computed minimum ventilation requirements by area.

TABLE 83

MINIMUM VENTILATION REQUIREMENTS

BLDG HEIGHT (FT)	OPER AREA (CFM)	MECH AREA (CFM)	GEN STOR AREA (CFM)	BLDG TOTAL (CFM
30	21,900	23,100	35,000	80,000
40	21,900	30,800	46,667	99,367
50	21,900	38,500	58,333	118,733
60	21,900	46,200	70,000	138,100

Ventilation requirements for the general storage area were specified at five percent per hour to reflect the reduction in the manpower per cubic foot ratio and the reduction in process load requirements. Hourly values for ventilation, heating, and cooling sensible loads were calculated by the ECUBE simulation using Equation (18).

$$Q = 1.08\ CFM(t_{OA} - t_{RM})/1000 \qquad (18)$$

where:

Q = Heat load in thousands of BTU's per hour

CFM = Minimum ventilation requirement in cubic feet per minute

t_{OA} = Outside air temperature in ^{o}F

t_{RM} = Room air temperature in ^{o}F

Outside air temperature is taken from the weather data included with ECUBE and the room temperature is calculated as part of the simulation.

The maximum cooling loads due to ventilation are shown in Table 84.

TABLE 84

MAXIMUM VENTILATION SENSIBLE COOLING LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	346	499	758	1,603
40	346	665	1,006	2,017
50	346	832	1,255	2,433
60	346	998	1,516	2,860

Table 85 shows the maximum heating loads due to infiltration.

TABLE 85

MAXIMUM VENTILATION SENSIBLE HEATING LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	1,537	1,622	2,274	5,433
40	1,537	2,162	3,019	6,718
50	1,537	2,703	3,777	8,017
60	1,537	3,243	4,535	9,315

In accordance with EATG specification, no humidification loads were calculated for the building; however, dehumidification loads required to limit the relative humidity level in the mechanized area to no more than

50 percent were calculated. No dehumidification was included for either the operating area or the general storage area of the warehouse. ECUBE computed hourly values for the dehumidification loads resulting from outside air infiltration by using Equation (19).

$$Q = 0.68\ CFM(W_{OA} - W_{RM})/1000 \qquad (19)$$

where:

Q = Heat load in thousands of BTU's per hour

CFM = Minimum ventilation requirement in cubic feet per minute

W_{OA} = Specific humidity of the outside air in grains of moisture per pound of dry air

W_{RM} = Specific humidity of the room air in grains of moisture per pound of dry air

Specific humidity of outside air is calculated based on weather data included with ECUBE, and room specific humidity is calculated as part of the simulation.

The maximum dehumidification loads for ventilation air are shown as in Table 86.

TABLE 86

MAXIMUM VENTILATION LATENT COOLING LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	0	1,552	0	1,552
40	0	2,070	0	2,070
50	0	2,587	0	2,587
60	0	3,100	0	3,100

Transmission Loads. Transmission loads for the warehouse facility were calculated in hourly increments by ECUBE using Equation (20).

$$Q = (U_W A_W + U_R A_R)(t_{OA} - t_{RM})/1000 \quad (20)$$

where:

Q = Heat load in thousands of BTU's per hour

U_W = Coefficient of thermal conductivity for walls (U_W = 0.10 BTUH /sq ft)

A_W = Surface area of zone perimeter walls

U_R = Coefficient of thermal conductivity for the roof (U_R = 0.075 BTUH /sq ft)

A_R = Surface area of roof over the zone

t_{OA} = Temperature of the outside air in ^oF

t_{RM} = Temperature of the room air in ^oF

Calculated design values for heating and cooling transmission loads are summarized in Tables 87 and 88.

TABLE 87

DESIGN TRANSMISSION COOLING LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	241	388	1,202	1,831
40	241	379	1,150	1,770
50	241	360	1,072	1,673
60	241	333	1,006	1,580

TABLE 88

DESIGN TRANSMISSION HEATING LOADS

BLDG HEIGHT (FT)	OPER AREA (MBTUH)	MECH AREA (MBTUH)	GEN STOR AREA (MBTUH)	BLDG TOTAL (MBTUH)
30	3,070	2,734	7,436	13,240
40	3,070	2,920	7,749	13,739
50	3,070	3,105	8,089	14,264
60	3,070	3,303	8,416	14,789

Load Profiles. The load values for motors, lights, and people presented in the sections above represent full load values and do not account for load diversity and variances in operating level. In order to calculate hourly values for these loads, load profiles were a necessary input parameter to the ECUBE simulation. For motor loads, due to diversity of operation, a load factor of 75 percent was used during all day shift hours and a load factor of 40 percent was used during night shift and weekend hours. Light loads were calculated at a 100 percent factor during all working hours and people loads were proportioned directly to shift manpower levels of 80 percent during day shifts and 20 percent during night and weekend shifts.

HVAC Energy Requirements

The next step in the design process was to evaluate the peak cooling and heating loads, and the yearly energy requirements of the warehouse for the four building heights. This was done using the ECUBE energy analysis computer program. The peak loads and energy requirements of the HVAC system were evaluated for varying thicknesses of insulation, prechilling the warehouse before the workday versus no prechilling, and the effect of using an enthalpy economizer.

Before using the ECUBE computer program to evaluate the peak cooling and heating loads and energy requirements, the warehouse radiant heat storage capacity and design temperatures had to be established. These are the first two topics of this section. Next an explanation of the ECUBE energy analysis program is presented. The heating and cooling peaks for the HVAC system, as determined by the ECUBE computer program, are discussed next. The contribution of the different cooling loads to the peak HVAC load is then analyzed. Finally, the effects of the building height and mass on the temperature, the variation of insulation, prechilling versus non prechilling, and use of economizer are covered.

Building Design Temperature. The building design temperature has a great effect on the load on the HVAC system. Two sets of design temperatures were established for the warehouse. For the air-conditioned part of the warehouse the temperature range was established as 65°F to 80°F. This air-conditioned area consisted of the operating area and the mechanized area, except for some total energy systems where air conditioning the whole building was analyzed. The general storage area was maintained

at 55°F in the winter and ventilated only in the summer. This ventilation system had enough fans to maintain the floor level temperature at approximately one degree more than the outside temperature. For the Norfolk area, this means that the floor level temperature was in the 90°F to 95°F range several times during the summer months. The difference in design temperatures between areas was established because of the large numbers of people and high activity in the operating area and mechanized area and small numbers of people and low activity in the general storage area.

Building Heat Storage. Part of the heat given off by the internal loads (motors, people, and lights) is not an instantaneous load on the HVAC system. It is stored by the building and re-emitted at a later time to become a load on the HVAC system. This is true because the heat given off by the motors, people, and lights is partly radiant heat and partly convective heat. The radiant heat is absorbed by surrounding parts of the building and stored items to be re-emitted later. The percentage of radiant heat given off by electric motors, people, and lights varies. Fifty percent of the heat given off by motors is radiant heat, while 67 percent of the heat given off by people and 66 percent of the heat given off by lights is radiant heat (ASHRAE, 1972a:422).

The time required for the absorbed heat to be re-emitted and become a load on the HVAC system is determined by the mass of the building and its contents. This building has light weight walls and roof, but the large amount of stored items provides great mass; so, the building was considered medium-heavy, which means it will take an average of five hours for all the radiant heat to become a load on the HVAC system. To calculate the load on the HVAC system due to one of the mentioned internal loads,

Equation (21) was used (ASHRAE, 1972a:422).

$$Q = \%R(hr_1 + hr_2 + hr_3 + hr_4 + hr_5)/5 + \%C(hr_5) \quad (21)$$

where:

Q = Total load on HVAC system in BTUH

%C = Percentage of heat which is convective

%R = Percentage of heat which is radiant

hr_1 = Total heat given off four hours before in BTUH

hr_2 = Total heat given off three hours before in BTUH

hr_3 = Total heat given off two hours before in BTUH

hr_4 = Total heat given off one hour before in BTUH

hr_5 = Total heat given off at hour being considered

This equation was used with the ECUBE computer program to time integrate the motor, people, and lights for the building storage capacity. ECUBE is discussed in the next section.

ECUBE Computer Program. The energy requirements of the building and the mechanical equipment selection were evaluated using the ECUBE75 computer program. ECUBE75 is an energy analysis and economics program written and owned by the American Gas Association, Arlington, Virginia 1975. The economic portion of the program was not used for this study. The energy analysis portion of the program is divided into two parts, Part I - Energy Requirements and Part II- Equipment Selection and Energy Consumption.

The input for the Energy Requirements (ER) subprogram consists of a weather tape, the cooling, heating, and electrical loads developed in the "HVAC Loads" section of this report, and how these loads vary with time or temperature. The weather tape is a computer data tape from the National

Climatic Center, which contains the outside air dry bulb temperature, relative humidity, and the percentage of cloud cover for each hour of the year for the locality being studied. The internal peak cooling and electrical loads (people, lights, and machinery) are developed in the "HVAC Loads" section and the profiles of their hourly variation for a year are developed in the "Material Handling Equipment and Personnel" section. These profiles were time integrated for heat storage as explained in the preceeding section. The exterior loads, those based on outside weather conditions (solar, transmission, and infiltration), are the next inputs for ECUBE. For the solar load, the input is the equivalent temperature differentials, the exposure, and the shading factors of the walls and roof and the latitude of the building being studied. ECUBE uses this input and the weather tape to generate the solar load. For transmission and outside air infiltration, the heat gain or loss for at least two given outside air dry bulb temperatures and wet bulb temperatures, as computed in the "HVAC Loads" section, and the temperatures themselves are inputs for both the heating and cooling loads. ECUBE straight line extrapolates from these two points to determine the heat gain or loss at other temperatures.

For a given hour of the year, ECUBE computes the internal and solar cooling loads, determines if the transmission and infiltration are cooling or heating loads and calculates their value. The loads are added algebraically to give either a cooling or heating load. The electrical demand is also computed for the hour. ECUBE computes these values for each hour of the year and tabulates all the values computed.

The Energy Requirements subprogram will also evaluate the effects of thermostat setup and setback, periodic HVAC system shutdown, and an enthalpy economizer. For temperature setup or setback and system shutdown, ECUBE can compute transient heat storage and temperature drift and how long it takes for the HVAC system to remove the stored heat once it is back on. ECUBE can also simulate an enthalpy economizer and the resultant reduced cooling load on the HVAC system.

The normal output for the Energy Requirements subprogram consists of each month's and the year's peak cooling, heating, and electric load and when they occurred, the cumulative value for each load type, and the peak value per square foot of floor area for all the different cooling, heating, and electrical loads.

The Equipment Selection and Energy Consumption (ESEC) subprogram simulates the operation of the mechanical equipment for a year to meet the energy requirements of Part I. ESEC determines the building total energy consumption and performance characteristics of the mechanical equipment. ESEC can simulate the operation of generators, chillers, boilers, and auxilliary equipment. The generators are inputs by giving the rated output load in kilowatts, input heat required at rated load, recoverable heat at rated load, and the partial load curves in percentage of the rated value. The chillers are modeled the same way, except that if there are no generators the rated input value is given in kilowatts of electricity. The boiler input is also the same as the generator's except there is no recoverable waste heat value.

In addition to the equipment inputs, one or two fuels and their heating values are inputs. The number of different systems (up to four), the number

of units for each type of equipment, and operating schedules are inputs. The operating schedule tells ECUBE which order the different units will turn on, at what load level the units turn on, and, if more than one unit is running, how the load will be shared.

ESEC output contains the building total fuel and electrical consumption for a year. It also tells how many hours each unit of mechanical equipment ran during the year, if and for how many hours a systems capacity was exceeded, and how many hours of the year each unit was partly loaded and the percentage of full load the unit was operating at.

Peak Cooling Loads. The peak cooling loads computed by ECUBE were used to size the air conditioning equipment. These peak loads are presented in Table 89.

TABLE 89

PEAK COOLING LOADS

BLDG HEIGHT (FT)	OPER AREA (TONS)	MECH AREA (TONS)	GEN STOR AREA (TONS)	BLOCK LOAD (TONS)
30	904	1,492	0	2,247
40	903	1,184	0	1,916
50	901	976	0	1,722
60	900	782	0	1,667

As can be seen from Table 89, the mechanized area and building peak cooling loads decrease as building height increases. This happens because the internal loads of motors, people, and lights in the mechanized area are the major contributing loads. As the building height increases, the level

of mechanization for the mechanized area decreases, and therefore the number of motors and people decreases. The decrease in these loads more than offsets the increase in the other loads resulting from increased building height. The slight decrease in the operating area peak load is due to the increased roof shading as the rest of the building's height increases. It can also be seen from Table 89, that the building block load is less than the sum of the peak loads for the different areas. This occurs because the peak loads for the areas occur at different times of the day, so the building block load is a combination of the peak load from one area and a partial load from the other area.

ECUBE also analyzed the building heating requirement for all four building heights and determined that none of the buildings required heating. The heat gain from the internal loads was more than sufficient to offset the heat losses due to transmission and outside air infiltration. This will be discussed further in this section.

Besides the overall peak HVAC loads of each area and the total building, ECUBE also determines the peak values of the contributing loads. This information was used to determine the major load in each area. This analysis is shown in Tables 90, 91, 92, and 93 for the peak cooling loads. The tables show that the internal loads are the major cooling loads in the operating area and the mechanized area. As the building height increases, the internal loads in the mechanized area decreases because of fewer motors and people, but it is still more than half of the total cooling design peak load. These internal loads consist of heat given off by motors, lights, and people with lights and motors being the major loads and people being a small percentage of the total internal loads. In the unmechanized

TABLE 90

COOLING LOAD BREAKDOWN OF 30 FOOT BUILDING *

(PERCENT)

	SOLAR	INTERNAL	TRANSMISSION	OUTSIDE AIR
Oper Area	18	76	2.5	3.5
Mech Area	11	75	2	12
Gen Stor Area	48	35	10	7

TABLE 91

COOLING LOAD BREAKDOWN OF 40 FOOT BUILDING *

(PERCENT)

	SOLAR	INTERNAL	TRANSMISSION	OUTSIDE AIR
Oper Area	18	76	2.5	3.5
Mech Area	12	67	2.5	18.5
Gen Stor Area	44	37	10	9

* The values are percentages of the area design peak load

TABLE 92

COOLING LOAD BREAKDOWN OF 50 FOOT BUILDING *

(PERCENT)

	SOLAR	INTERNAL	TRANSMISSION	OUTSIDE AIR
Oper Area	18	76	2.5	3.5
Mech Area	13	60	2.5	23
Gen Stor Area	41	41	8	10

TABLE 93

COOLING LOAD BREAKDOWN OF 60 FOOT BUILDING *

(PERCENT)

	SOLAR	INTERNAL	TRANSMISSION	OUTSIDE AIR
Oper Area	18	76	2.5	5.5
Mech Area	14	53.5	2.5	30
Gen Stor Area	40.5	40.5	8	11

* The values are percentages of the area design peak load

general storage area the internal loads are still significant, but the solar load is larger, except for the 60 foot building where they are the same. This reflects the much smaller numbers of motors and people in the area. In fact, even though the general storage area is one and one-half times the area of the other two areas combined, it would only require, if air-conditioned, one-third of the total amount of air conditioning the other two areas require in the 30 foot building and one-half the amount the other two areas require in the 60 foot building. This shows that the degree of mechanization greatly affects the internal loads and the amount of air conditioning required.

The peak value of the solar cooling load and transmission cooling load are directly related to the amount of insulation in the roofs and walls. The transmission load is only large enough to be of significance in the general storage area, but the solar load is a significant cooling load in all areas and the largest cooling load in the general storage area. So the optimum thickness of insulation can produce significant savings, and this was evaluated and is discussed later in this section.

The air ventilation cooling load is a small contribution to the design peak cooling load in the operating and general storage areas, but is the second largest load in the mechanized area. This occurs because the mechanized area is the only area with humidity control, and it requires an extra amount of air conditioning to dehumidify the outside air.

Once the peak cooling loads were established and an analysis of these peak cooling loads completed, the building properties that affect the HVAC system and modifications to the HVAC system and operating schedule were studied.

Building Temperature Variation. The first building property studied was temperature variation. Both the temperature variation with time and with height above the floor level were evaluated. The temperature variation with time study was made to determine where the building temperature would drift within the design temperature range at different times of the year. As previously mentioned, the first thing established was that no heating was required, so the temperature never drifted below 65°F in the operating and mechanized areas and 55°F in the general storage area. Air conditioning was required in the operating and mechanized areas for most of the year, and the general storage ventilating fans were used frequently even during spring and fall months. Again this occurs because the large heat gain from the internal loads more than offsets any heat losses.

Another result of the temperature variation with time study was the determination that the building temperature is very stable. When the HVAC system is off, which it was from 2400 hours to 0800 hours, the temperature drifts very little. During the shutoff period, the temperature in the building never drifted more than two degrees. The building temperature is stable because the large mass of stored material provides a large heat storage capacity. A large amount of heat must be stored or lost to change the temperature of the large mass, and because it is in contact with stored items the air temperature will be approximately the same as the temperature of the stored mass.

The temperature variation with height above the floor level was studied next. Warm air, which is less dense, tends to rise so the temperature at the roof is higher than the temperature at the floor level. At 30 to 60 foot building heights, this temperature difference is significant. Table 94

shows the temperature difference for the four building heights.

TABLE 94

INSIDE TEMPERATURE AT CEILING

	TEMP AT 30 FEET (°F)	TEMP AT 40 FEET (°F)	TEMP AT 50 FEET (°F)	TEMP AT 60 FEET (°F)
80°F At Floor Level	89	90.5	91.5	92.5
90°F At Floor Level	99	100.5	101.5	102.5

These temperatures in Table 94 were computed using a temperature rise of one percent up to 15 feet above the floor level and one-tenth of a degree per foot of height above 15 feet (ASHRAE, 1965:26-10). These temperatures will have an effect on men riding material handling cranes and on material stored at higher levels.

Insulation Test. The next study was to determine the optimum insulation thickness for the building. To make the insulation test, the insulation thickness in only the roof was varied. This was done because most of the solar and transmission heat gain or loss is through the roof and a small percentage is through the walls. This is true because of three design conditions. The roof area is approximately four and one-half to nine times larger than the wall area, depending on building height. Also, the roof was considered medium colored while the walls are light colored, and the roof receives more direct sunlight. Because of all this, it was decided that varying the wall insulation would have no appreciable cost benefits.

To test the insulation, the building energy requirements were evaluated

using ECUBE for three coefficients of heat transfer (U value) of the roof. The values used were 0.05, 0.075, and 0.10 BTU's per hour per square foot. This variation of roof insulation had little effect on the heating requirements. For the 0.05 and 0.075 U values there was no heating required, and at 0.10 there was only a small amount of heating needed during one month for three of the four building heights. For cooling, there was a noticeable difference in energy requirements. There was no significant changes in peak cooling loads. The peak cooling loads changed one to seven percent depending on building height. This does not require any resizing of HVAC equipment, so there was no difference in costs. There was a difference in the total cooling required per year and these differences are presented in Table 95.

TABLE 95

INSULATION TEST

TOTAL COOLING REQUIRED

(TONS/YR)

U VALUE (BTU/HR-SQ FT)	30 FOOT BLDG	40 FOOT BLDG	50 FOOT BLDG	60 FOOT BLDG
0.05	2,181,710	1,770,478	1,586,943	1,447,856
0.075	2,140,184	1,763,825	1,595,444	1,454,650
0.10	2,176,815	1,765,748	1,599,331	1,463,587

Table 95 shows definitely that the 30 foot and 40 foot buildings are over insulated at a U of 0.05. The additional cooling required during the winter to remove the extra trapped heat from the internal loads more than offsets

the reduced cooling load in the summer. A U of 0.075 results in the least cooling per year for the 30 and 40 foot buildings, and a U of 0.05 results in the least cooling per year for the 50 and 60 foot buildings. Since the U of 0.075 was best for two of the four building heights and takes three-quarters of an inch less insulation (see "Roofing" section), the 0.075 BTU's per hour per square foot value was used for all building heights in determining the energy requirements.

Prechilling. Prechilling is a method of operating the HVAC system to possibly reduce peak energy consumption and total yearly consumption. Normally, the HVAC system is off when there are no people in the building. For the warehouse, this occurs from 2400 hours to 0800 hours. Prechilling means turning the HVAC system on before the people arrive and prechilling the building. Then, the heat storage capacity of the chilled building can absorb some of the heat gain during the day lowering the peak cooling loads on the HVAC system.

For the warehouse, two hours of prechilling (turning HVAC system on at 0600 hours) was compared to no prechilling. The results were inconclusive. The peak cooling load was decreased approximately ten percent for the 30 and 40 foot buildings, but the peak cooling load for the 50 and 60 foot buildings was unchanged. The difference in annual energy savings was so small as to be almost unmeasurable. The peak kilowatt demand was slightly reduced for all four building heights, and this is shown in Table 96.

TABLE 96

PRECHILL VERSUS NO PRECHILL

PEAK KILOWATT DEMAND

(KW)

	30 FOOT BLDG	40 FOOT BLDG	50 FOOT BLDG	60 FOOT BLDG
Prechill	6,055	5,370	5,037	4,733
No Prechill	6,639	5,816	5,363	4,925

This is a slight decrease, but could help reduce costs if the building peak kilowatt usage is into a peak kilowatt penalty area. Possible savings could not be evaluated because of not having detailed price information for electricity. A savings might be realized with prechilling because some of the high kilowatt demand and total yearly consumption now occurs during early morning hours where off-hour electric rates could reduce the operating cost significantly. However, this would require detailing electric rates and a more in depth study of the electric consumption.

Economizer Cycle. An evaluation of energy savings using an enthalpy economizer was made. The enthalpy economizer shuts down the chiller units and uses unconditioned outside air to cool with, when the enthalpy, BTU's per pound mass of air, of outside air is less than the enthalpy of the air in the conditioned space. It is like opening the windows on a cool day and saves the energy to run the chiller units. Table 97 shows the reduction in the annual total cooling required using an enthalpy economizer.

TABLE 97

ECONOMIZER SAVINGS

ANNUAL COOLING REQUIRED

(MBTUH)

	30 FOOT BLDG	40 FOOT BLDG	50 FOOT BLDG	60 FOOT BLDG
Without Economizer	36,815,609	29,641,150	25,067,311	21,488,644
With Economizer	25,682,210	21,165,900	19,143,461	17,455,807
Percent Savings	30%	29%	24%	19%

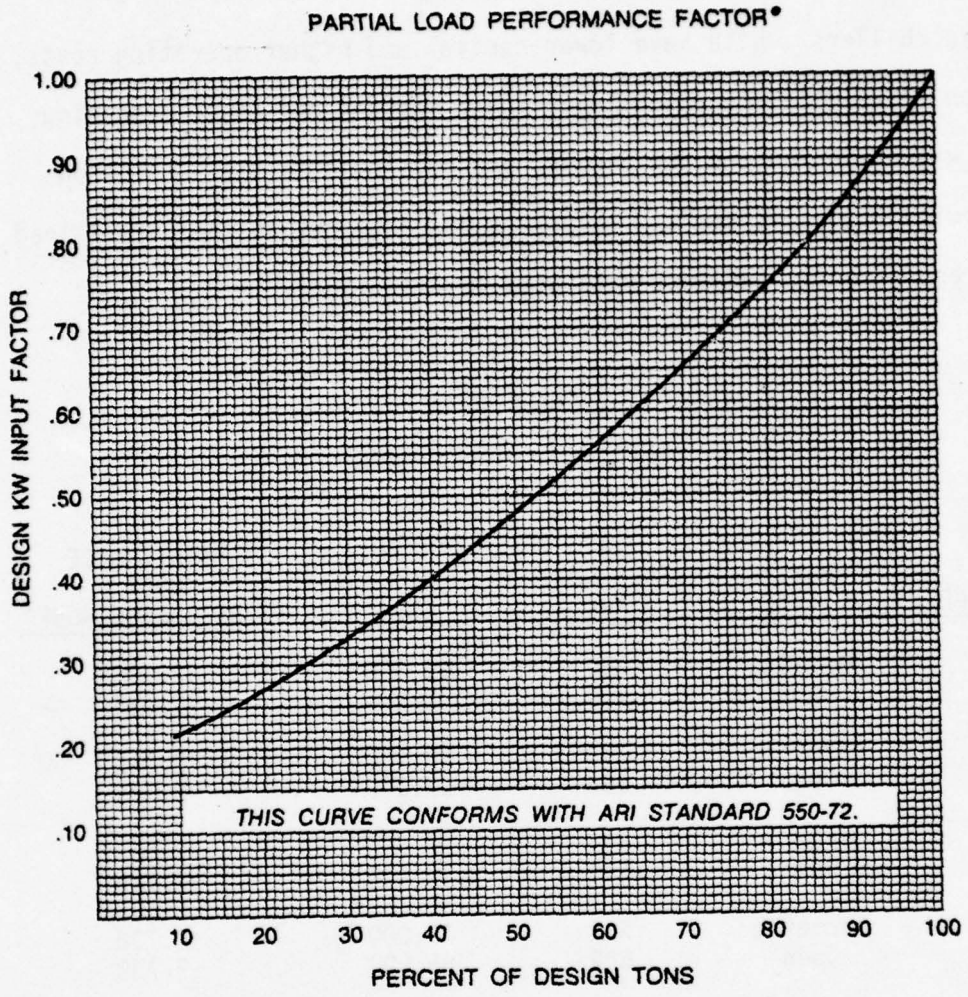
As can be seen from Table 97 , very substantial savings in energy consumption result from using an enthalpy economizer. The decrease in the amount of savings as the building height increases is due to the lower level of mechanization in the higher building heights. As mechanization decreases the internal cooling load decreases, which reduces the air conditioning required in winter when the economizer provides the greatest savings. Because of the large savings in energy consumption, all the HVAC systems designed for the warehouse include an enthalpy economizer.

Chiller Units

Two types of chiller units were included in the equipment analysis of this study. Electrically driven, centrifugal chillers were used for the commercial power analysis and absorption chillers were used in the total energy analysis. Unit performance values and cost data reflect York equipment due to the excellent cooperation and support received from this manufacturer. This section discusses the important performance factors for the units used, and then lists capital costs and maintenance cost factors.

Centrifugal Chillers. Unit capacity, full load energy requirement, partial load performance, capital cost, and maintenance costs were the important factors required for analysis of the electric chiller systems. This analysis included both hermetic chillers and open drive chillers. Unit capacities studied ranged from 350 tons to 1050 tons and full load kilowatt requirements ranged from 274 kilowatts to 796 kilowatts. A complete listing is shown in Table 98. Partial load operating characteristics of York centrifugal chillers meet ARI standard 550-72. Figure 30 is a graph of the estimated performance values.

Unit purchase and maintenance cost data was provided by the Cincinnati, Ohio office at the Engineered Machinery Division, York Air Conditioning and Refrigeration Group, Borg-Warner Corporation (Yerian, 1976). Unit selection was limited to the basic model for each required tonnage. It is possible to change condensor and evaporator bundles for a given unit. These changes increase the capital costs with the benefit being a reduction in electrical consumption. This refinement was not included as part of this design study. A similar trade off between the cost factors for



• Estimated typical unit partial load performance. Only one point, normally full load, will be guaranteed.

$$\text{Percent Design Tons} = \frac{\text{Part Load Tons}}{\text{Design Tons}} \times 100\%$$

Part Load KW = Design Full-Load KW x Design KW Input Factor

FIGURE 30 ELECTRIC CHILLER PARTIAL LOAD OPERATING CHARACTERISTICS *

* Reference (York, 1973b:44)

hermetic chillers, which have lower capital and higher operating costs, and open drive chillers which have higher capital and lower operating costs, was evaluated and the results are developed in the section on "Commercial Power Systems". Table 98 summarizes the tonnage, full load power requirements, and cost data used in this study.

TABLE 98

ELECTRIC CHILLER DATA

TONNAGE	CHILLER TYPE	FULL LOAD KW	CAPITAL COST ($)	MAINTENANCE COST ($/OPERATING HOUR)
1050	Hermetic	796	85,600	2.936
	Open	730	105,600	2.936
950	Hermetic	723	84,900	2.875
	Open	664	97,100	2.875
850	Hermetic	639	82,600	2.825
	Open	590	95,410	2.825
825	Hermetic	654	76,000	2.738
	Open	589	88,000	2.738
800	Hermetic	615	75,100	2.600
	Open	563	87,100	2.600
725	Hermetic	574	69,000	2.379
	Open	523	77,800	2.379
675	Hermetic	548	67,000	2.260
	Open	495	73,400	2.260
620	Hermetic	513	57,500	2.161
	Open	480	67,300	2.161
575	Hermetic	452	55,600	2.088
	Open	433	64,700	2.088
550	Hermetic	439	54,000	1.985
	Open	421	62,300	1.985

TABLE 98 CONTINUED

TONNAGE	CHILLER TYPE	FULL LOAD KW	CAPITAL COST ($)	MAINTENANCE COST ($/OPERATING HOUR)
525	Hermetic	414	52,900	1.813
	Open	393	59,300	1.813
400	Hermetic	320	47,700	1.650
	Open	303	50,900	1.650

Absorption Chillers. Unit capacity, full load steam requirements, partial load performance, capital cost and maintenance costs were for absorption chillers were required for the study of total energy system applications. Absorption chillers ranging from 311 tons to 1148 tons were used in the study. Full load steam requirements ranged from 5650 pounds per hour at 12 pounds per square inch gauge to 21,000 pounds per hour at 12 pounds per square inch gauge. Partial load requirements are shown in Figure 31. Unit purchase and maintenance costs were provided by York (Yerian, 1976). Table 99 summarizes the tonnage, full load steam requirements, and cost data for the units used in this study.

TABLE 99

ABSORPTION CHILLER DATA

TONNAGE	FULL LOAD STEAM REQ. (LB/HR @ 12 PSIG)	CAPITAL COST ($)	MAINTENANCE COST ($/OPERATING HOUR)
1148	21,000	113,200	3.535
960	17,600	96,900	3.440
908	16,600	92,800	3.145
794	14,600	83,700	2.935
704	12,800	75,900	2.708
617	11,300	67,600	2.485
565	10,300	62,400	2.168
410	7,500	49,600	1.890
363	6,650	45,200	1.718
311	5,650	41,600	1.568

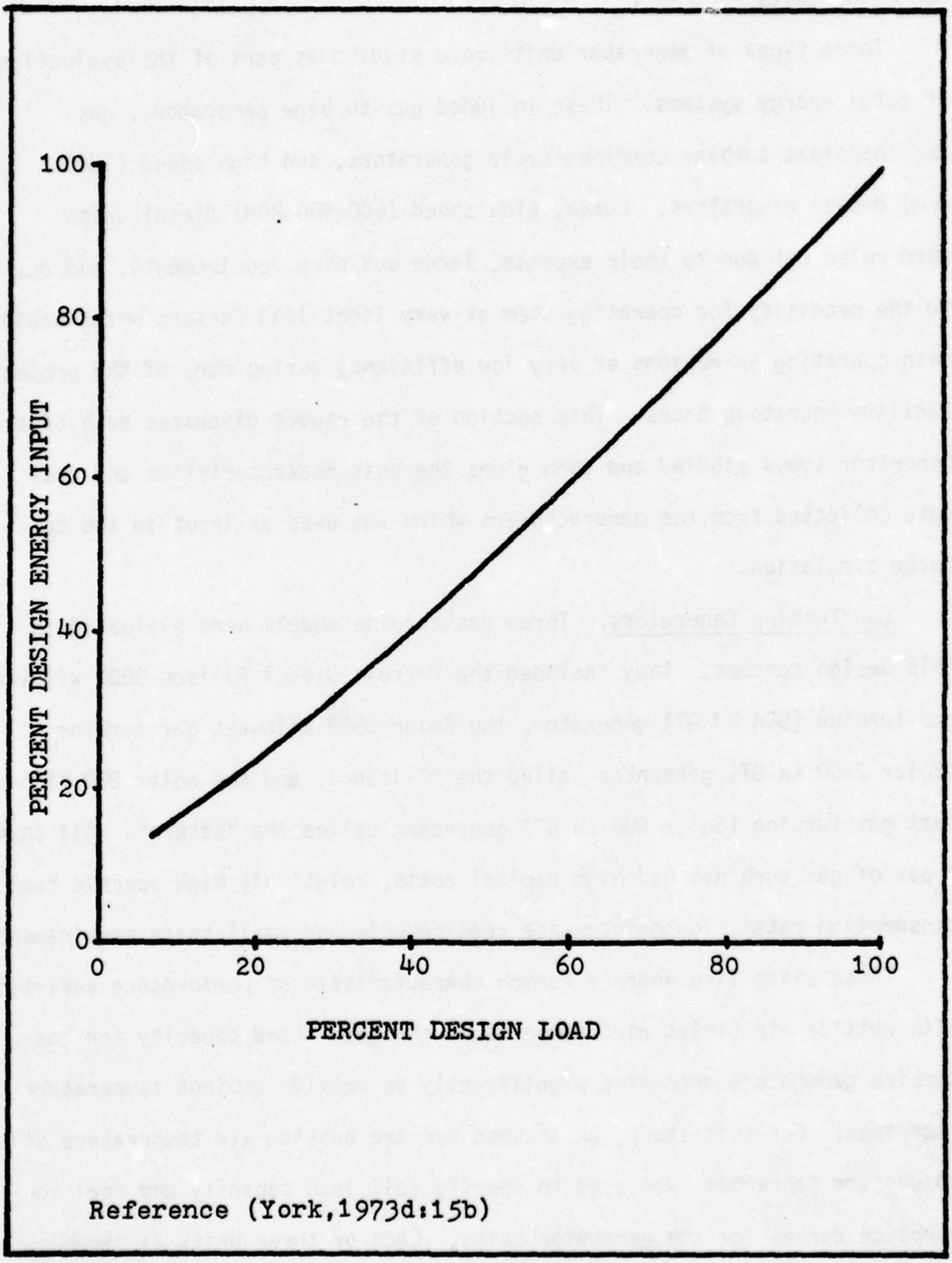


FIGURE 31 ABSORPTION CHILLER
PART LOAD STEAM CONSUMPTION

Generator Units

Three types of generator units were studied as part of the evaluation of total energy systems. These included gas turbine generators, gas turbine/steam turbine combined cycle generators, and high speed (1800 RPM) diesel generators. Large, slow speed (600-900 RPM) diesel units were ruled out due to their expense, large building requirements, and due to the necessity for operating them at very light load factors which would mean operating in regions of very low efficiency during many of the projected facility operating hours. This section of the report discusses each of the generator types studied and then gives the unit characteristics and cost data collected from the manufacturers which was used as input to the computer simulation.

Gas Turbine Generators. Three gas turbine models were evaluated in this design concept. They included the Detroit Diesel Allison 3000 kilowatt gas turbine (DDA KW GT) generator, the Solar 2500 kilowatt gas turbine (Solar 2500 KW GT) generator called the "Centaur", and the Solar 800 kilowatt gas turbine (Solar 800 KW GT) generator called the "Saturn". All three types of gas turbines had high capital costs, relatively high specfic fuel consumption rates, low maintenance requirements and small space requirements.

These units also share a common characteristic of performance variation with outside air (inlet air) temperature changes. Load capacity for gas turbine generators decreases significantly as outside ambient temperature increases. For this study, an assumed average outside air temperature of 80 degrees Fahrenheit was used to specify full load capacity and fuel consumption curves for the generator units. Each of three units is capable of multi-fuel operation. The basic fuels for all units include either

number 1 or number 2 gas turbine, diesel, or furnace oil. Other liquid fuels suitable for use include, Jet A, A-1, Jet B, JP-4, and JP-5. By changing the fuel control systems and burner nozzles, natural gas can be used. There is a possibility of using heavy grade, low sulphur fuel oils; however, this would increase the maintenance costs on the units. Another important factor in gas turbine ratings is altitude. For this study of applications in the Norfolk, Virginia area, ratings were based on sea level operation.

One last characteristic shared by all gas turbine units is that most of the waste heat from the generator exits through the exhaust. This means that the BTU's available are at a temperature high enough ($850^{o}F$-$950^{o}F$) to be easily reclaimed and used for absorption air conditioning.

DDA-3000 KW GT. DDA-3000 KW GT generators were evaluated in sets of either three or four units, as necessary, to supply building requirements and include one backup unit. Price data was obtained from Clarke GM Diesel, Inc., Cincinnati, Ohio, and from Turbine Power Systems Co., Maineville, Ohio (Wood, 1976)(Mendenhall, 1976). Older versions of these units are in use by the Navy as portable generating stations for ships in port in Norfolk, Virginia.

Solar-2500 KW GT and Solar-800 KW GT. Solar gas turbine generators were evaluated in sets of four units for the 2500 KW, Centaur, size and in sets of seven to ten units for the 800 KW, Saturn, size depending on building requirements. One backup unit was added to each system evaluated. Price data for the Solar equipment was provided by the Solar Division of International Harvester Company (Kearns, 1976). Older versions of the 800 KW generators have been in use in a total energy system installed at

the U.S. Air Force Satellite Control Facility, Sunnyvale, California.

Gas Turbine/Steam Turbine Generators. Currently the Solar Division of the International Harvester Company is working on a company funded development program to build a small combined cycle gas turbine/steam turbine generator capable of thermal efficiencies in excess of 40 percent. These units are to be marketed at a competitive price per horsepower versus gas turbine generators and have a fuel savings exceeding 35 percent. Solar is developing combined cycle units based on both the Saturn and the Centaur gas turbine prime movers. Initial field evaluation units are expected to be tested in 1978-1979 and production units are forecast for 1980 (Doorly, 1976). The gas turbine/steam turbine generators operate with the same capabilities and restrictions as the basic gas turbine units cited above; however, the waste heat in the exhaust is converted to steam and used to drive a slave steam turbine unit. Again, price data was supplied by Solar (Kearns, 1976). These units were included in the study due to their projected availability within the development time required for warehouse design and due to their marked increase in overall system thermal efficiency which would translate directly into operating cost savings. Unit sizes studied included a 3750 kilowatt Centaur set and a 1200 kilowatt Saturn set.

Diesel Generators. Two models of high speed (1800 RPM) diesel generators were evaluated. One model was the Cummins Engine Company, KTA 2300 generator set rated at 690 kilowatts for continuous duty. The other unit was the Detroit Diesel Allison, 16V-149T generator set rated at 795 kilowatts for continuous duty. The diesel generator sets had relatively low capital costs, low specific fuel consumption, high maintenance costs,

and larger space requirements. Fuel for the diesel units is normally number 2 diesel oil; however, Cummins is testing the use of number 6 fuel oil in their engine (Castin, 1976).

The diesel generator sets are relatively unaffected by changes in altitude below 5000 feet mean sea level and changes in outside air (inlet air) temperature below 100 degrees Fahrenheit. The primary disadvantages to diesel generators for a total energy power system for warehouse application is that much of the waste heat from the diesel is removed by the cooling water jacket. This water leaves the engine at an average temperature of approximately 180 degrees Fahrenheit. This temperature is too low for efficient operation of absorption air conditioning which comprises most of the waste heat energy usage in the warehouse. Waste heat recovery, using exhaust heat only was studied.

None of the diesel generator systems evaluated had enough recoverable waste heat using exhaust heat only to meet the peak load requirements of the absorption equipment. Therefore, supplementary firing of the waste heat boilers was necessary to meet system needs.

Cummins 690 KW Diesel. Cummins 690 KW Diesel units were evaluated in sets of nine to 12 units as required to supply building electric loads. Two backup units were included to meet maintenance needs. Price data was obtained from the Cummins Engine Company, Inc., Columbus, Indiana (Castin, 1976).

Detroit Diesel Allison 795 KW Diesel. Sets of seven to ten DDA-795 KW Diesel generator units were also studied. Again, two backup units were included to meet maintenance requirements. Price data was provided by Clarke GM Diesel, Cincinnati, Ohio (Wood, 1976).

Generator Performance and Cost Data. Performance and cost data as provided by the respective manufacturer for each of the generators studied is shown in Table 100.

TABLE 100

GENERATOR PERFORMANCE AND COST DATA

MANUFACTURER	TYPE	FULL LOAD POWER RATING (KW)	FULL LOAD FUEL CONSUMPTION* (GAL/HR)	CAPITAL COST ($/KW)	MAINT COST ($/KWH)
DDA	GT	3000	288	198	0.0015
Solar	GT	2500	280	230	0.0025
Solar	GT	800	98	230	0.0025
Solar	GT	2500	280	230	0.0025
	ST	1250		240	0.0025
Solar	GT	800	98	230	0.0025
	ST	400		240	0.0025
Cummins	D	690	52.2	210	0.0055
DDA	D	795	78.2	220	0.0055

* Specific gravity = 0.84 @ 60°F

Lower heating value = 132,000 BTU/Gal

Auxilliary HVAC Equipment

The auxilliary HVAC equipment includes all of the HVAC system components except for the chillers. This consists of the water pumps, cooling tower, air handlers and fans, boiler, and ducts and piping. The "HVAC System Design" section describes the equipment selection and sizing. This section lists the equipment selected and gives the costs of the equipment.

Pumps. Several water pumps were needed in each HVAC system to circulate the chilled water and the condenser water. Table 101 lists all the pumps used in the different HVAC systems, the pump peak input power, and the installed price of each pump. The values in Table 101 were used to select the required pumps for a HVAC system and to determine the pump's contribution to the building electrical consumption cost. An explanation of how these values were determined follows.

The flow rate, or gallons per minute, of each pump was specified at a 50 foot head, or pressure drop. The actual pumps for the HVAC systems have different flow rates and are overcoming different pressure drops. This made pricing complex; so, for ease of pricing the pumps were re-rated at a 50 foot pressure drop. This was accomplished using Equation (22) (Bell and Gossett, 1965:4).

$$(Q_2/Q_1)^2 = h_2/h_1 \qquad (22)$$

where:

Q_1 = Known flow rate in GPM

Q_2 = Unknown flow rate

h_1 = Head of known flow rate in feet

h_2 = Head of unknown flow rate in feet

TABLE 101

PUMPS

FLOW RATE (GPM)	PEAK INPUT POWER (KW)	INSTALLED COST ($)
450	7.76	1950
600	9.49	1950
650	10.28	1950
750	11.87	2050
800	12.66	2150
900	13.88	2351
1000	15.21	2550
1200	17.29	3060
1300	18.73	3315
1400	19.90	3570
1500	21.04	3875
1750	24.55	4463
2000	27.13	5100
2500	33.69	5250
3000	39.95	5400
3500	46.06	5567
4000	51.73	5733
4500	57.52	5867
4800	60.65	6000

So all the pump GPM's listed in Table 101 are based on a 50 foot head.

The input power in kilowatts was computed using Equations (23) and (24) (ASHRAE, 1972a:302).

$$BHP = GPM \times \Delta P/3960 \times Ep \quad (23)$$

$$KW = .7457 \times BHP/Em \quad (24)$$

where:

BHP = Brake horsepower

GPM = Gallons per minute

ΔP = Pressure drop in feet of water

Ep = Efficiency of pump

Em = Efficiency of motor

The pump and motor efficiencies were taken from tables (Hicks, 1971:255) (Smeaton, 1969:6-23). With these equations and efficiencies the input kilowatts were computed for the given flow rates.

The prices were computed from a manufacturer's purchase price and labor cost for installation. The purchase price was obtained from the Duriron Company for regular water, centrifugal pumps (Friedman, 1976). Installation costs were included by adding 50 percent to the initial purchase price (Craftsman, 1975:253). The one cost not shown in Table 101 is the maintenance cost which was also obtained from Duriron and is $75 per pump per year for all pumps. This cost consists of repacking the pump every six months and replacing bearings every two years.

Cooling Towers. Cooling towers were sized using two sets of specifications. Both sets of specifications were based on the Norfolk, Virginia design day of 95°F dry bulb temperature and 78°F wet bulb temperature (Carrier, 1972:15). For the electric chillers, two cell cooling

towers with the water entering at 95°F and leaving at 85°F were used. For the absorption chillers, because of the greater heat rejection, three cell cooling towers with the water entering at 100°F and leaving at 85°F were used. The towers and their costs used in the different HVAC systems are listed in Table 102.

TABLE 102

COOLING TOWERS

ELECTRIC CHILLERS		ABSORPTION CHILLERS	
FLOW RATE (GPM)	INSTALLED COST	FLOW RATE (GPM)	INSTALLED COST
6,000	$53,000	9,000	$110,000
7,000	$64,000	10,500	$135,000
8,000	$76,000	12,000	$140,000
9,000	$77,000	13,500	$135,000
10,000	$86,000	15,000	$165,000
		16,500	$180,000

These prices were obtained from the Marley Company, which specializes in cooling tower construction (Blanchard, 1976). We were also quoted an average maintenance cost of $1000 per year per cell for complete maintenance including water treatment, cleaning, and fan maintenance.

Air Handling Units and Fans. Air handlers for the air conditioning system and fans for ventilating the general storage area were the next items considered. The air handlers were sized based on 44°F entering water,

a ten degree water temperature rise. The air handling units are rated on maximum air flow in cubic feet per minute and the peak cooling capacity expressed in tons, while the fans are only rated by cubic feet per minute of air. Table 103 lists the air handlers and fans along with their peak input electrical power and their costs.

TABLE 103

AIR HANDLERS AND FANS

AIR FLOW (CFM)	COOLING CAPACITY (TONS)	PEAK INPUT POWER (KW)	INSTALLED COST
		Air Handlers	
45,000	150	31.6	$17,258
18,000	30	13.4	$12,033
50,000	100	38.5	$17,040
50,000	225	38.5	$21,993
50,000	175	38.5	$17,881
50,000	90	38.5	$16,628
50,000	125	38.5	$17,041
		Fans	
10,000	---	3.7	$ 1,610
16,000	---	5.7	$ 1,728
20,000	---	8.3	$ 2,150

The peak air handler and fan power inputs were obtained from Trane fan curves (Trane, 1971), using assumed static pressures of 2.75 inches of water for the air handlers (Lewis, 1976) and 0.75 inches for the fans. The assumed 2.75 inches of static pressure was based on 0.55 inches for the ductwork, 0.1 inches for the dampers, 0.5 inches for the filter, and 1.6 inches for the coil. The value of 0.75 inches static pressure for fans was used based on specifications recommended by Mr. William Binkley, owner of Binkley Distributing Company (Binkley, 1976). The installed cost for the air handlers was derived by obtaining the purchase costs from Trane (Albitz, 1976) and adding eleven percent for labor costs (Craftsman, 1975:255). A maintenance cost of $460 per unit per year was also obtained from Trane which includes changing filters and greasing of bearings.

Boilers. The boilers used were designed for standby heating and to provide perimeter heating. The boilers were sized to be capable of overcoming the wall transmission and air infiltration loss. These boilers and their costs are in Table 104.

TABLE 104

BOILER SYSTEMS

BLDG HEIGHT (FT)	OUTPUT HP *	BOILER COST
30	150	$18,513
40	195	$22,236
50	195	$22,236
60	225	$30,335

* One HP = 33,500 BTU/hr

Each one of the systems consists of three boilers and the costs are from the National Construction Estimator (Craftsman, 1975:250).

Pipes and Ducting. Because this was a design concept study, a detailed piping and ducting system was not designed or costed. To allow for the costs of the piping system, an approximate factor of 25 percent of total cost was used. Since the ducting in the warehouse would not be as extensive as the piping system, 15 percent of total cost was used for ducting. This makes the total cost factor for ducts and piping 40 percent of the total HVAC system cost.

HVAC System Design

This section presents the design approach used to size the HVAC equipment associated with the electric cnetrifugal chiller systems and the absorption chiller systems. To illustrate the design procedure, the best chiller system for the 30 foot building is developed at the end of this section.

The technical literature provided by several manufacturers is incorporated in this section but no direct reference is made since all pieces of equipment are thoroughly discussed and referenced in preceding sections. No cost data is presented since all component costs are developed in other sections.

Chiller Systems. The electric centrifugal chillers are presented first. The hermetic and open chillers were sized in the same manner; therefore, no distinction is made between these two chiller types.

Four sets of electric chiller sizes were evaluated for each building height. For system 1 of each height the first chiller was sized to provide for 25 percent of the cooling load and the remaining 75 percent load was divided equally between two larger chillers. A backup chiller was provided and was sized equal to one of the large primary chillers. System 2 for each building height had two chillers of equal size to provide for 50 percent of the cooling load and the remaining 50 percent of the load was provided for by one large chiller. The backup chiller was the same size as this large primary chiller. System 3 for each building height had 100 percent of the cooling load provided for by two equally sized chillers and one of the same sized units was used as a backup. For system 4 of each building height, three equally sized chillers provided for 100 percent of the

cooling load and a backup chiller of the same size was provided. Backup units were sized to allow any one of the primary units to be down for maintenance without loss of system performance.

The absorption chillers were designed differently than the electric chiller systems. For all systems of each building height 100 percent of the cooling load was provided by two chillers and an equally sized absorption chiller was provided as a backup. Chiller unit selection was based on nominal tonnage ratings at the following assumed operating conditions.

Chilled water leaving temperature = 44°F

Chiller water entering temperature = 54°F

Condenser water leaving temperature, electric chillers = 95°F

Condenser water leaving temperature, absorption chillers = 100°F

Condenser water entering temperature = 85°F

Fouling factor for both condenser and chilled water = .0005

Pump Selection. The pumps were sized based on chiller condenser and evaporator requirements at nominal tonnage ratings assuming two pass condensers and two pass evaporators. The condenser and evaporator (chilled) water flow, in gallons per minute (GPM), across the associated pressure drop was extracted from appropriate tables and graphs (York, 1973a)(York, 1973b)(York, 1973c)(York, 1973d)(York, 1975c). The total system water flow to the cooling tower is the sum of the condenser water GPM requirements of the chillers, including the backup chiller, plus 500 GPM from the freezer/cooler. An assumed head of 50 feet of water was used from the chiller units to the cooling tower and return. This assumption was based on typical specifications recommended in the article, "Specifications for Construction

of Modular Water Chilling Plant" (Solar, No date).

The primary supply pumps for the building were sized to meet the total chilled water GPM of all installed chillers. A head of 60 feet of water was assumed for the building chilled water circuits. This value was also selected from recommendations in the article on chilled water plant specifications (Solar, No date). The number of condenser pumps and evaporator pumps for the electric chiller systems and the absorption chiller systems were computed and sized as follows:

Electric chiller systems

Condenser pumps - 1 per chiller

Evaporator pumps - 1 per chiller

Primary supply pumps = 3 @ total chilled water GPM/3 plus one additional unit as a backup and to allow for system expansion

Cooling tower pumps = 2 @ total condenser water GPM/2

Absorption chiller systems

Condenser pumps - 1 per chiller

Evaporator pumps - 1 per chiller

Primary supply pumps = 4 @ total chilled water GPM/4 plus one additional unit as a backup and to allow for system expansion

Cooling tower pumps = 3 @ total condenser water GPM/3

Cooling Tower. The cooling towers were sized using Norfolk, Virginia design conditions.

Dry bulb temperature = $95^{o}F$

Wet bulb temperature = $78^{o}F$

The electric chiller system water entering temperature was assumed to be

95°F and the leaving temperature was assumed to be 85°F ($\Delta T = 10^{o}F$). For the absorption chiller systems, the water entering temperature was assumed to be 100°F and the leaving temperature was assumed to be 85°F ($\Delta T = 15^{o}F$).

The total GPM is equal to the system condenser water GPM plus 500 GPM from the freezer/cooler. The cooling towers were sized to include full operation of the backup chillers. The electric chiller systems required two cells per cooling tower (50 percent of the total GPM per cell). The absorption chiller systems required three cells per cooling tower (approximately 33 percent of the total GPM per cell).

Air Handling Units. The lack of a specific equipment layout from EATG precluded a detailed design of the air conditioning and ventilation systems. Typical systems were designed and scaled to provide an adequate data base for cost analysis. The required cooling tonnage and the required ventilation are discussed in the "HVAC Energy Requirements" section.

The air handlers were designed independently for the operating area, mechanized area, and the general storage area. The general storage area was equipped with air handling units in those buildings totally air-conditioned; for buildings having ventilation only in the general storage area, fans were used as discussed under the next subsection. For the operating area 36,000 CFM air handlers were used and the other two areas were assumed to have 50,000 CFM air handlers. These values were selected based on information received during a telephone interview with Mr. Jim Albitz, sales representative for the Trane Company. Mr. Albitz indicated that normally a minimum of 200 CFM per ton of unit capacity is required to insure reliable operation of the air handlers. The minimum number of air handling units per area is equal to the required tonnage of the respective area

divided by the tonnage of the air handling unit (Albitz, 1976). Minimum coil sizes exceeded building requirements by approximately 50 percent. Another selection method would have been to size the coils to meet the load and use a greater number of smaller air handling units to meet the CFM requirements; however, this would have been more expensive.

Fan Selection. The installed volume air flow provided by the fans in the general storage area was assumed to be 10,000 CFM for the 30 foot building, 16,000 CFM for the 40 foot building, and 20,000 CFM for both the 50 and 60 foot buildings. All fans were sized using an assumed static pressure of three-quarters of an inch of water. These assumed fan capacities were determined to be reasonable (Binkley, 1976) and the number of fans required per building height is consistent with typical industrial practice. The fans are ceiling mounted in the 30 acres of general storage area to provide adequate ventilation. Due to the lack of air conditioning in the general storage area excessively high temperatures during the summer working days were considered to be a potential personnel hazard. To offset this hazard, a ventilation system was selected to provide two air changes per hour. With two air changes per hour, the ventilation system was capable of extracting more heat than that generated by the building systems as determined by ECUBE with a temperature differential of five degrees Fahrenheit above abmient air temperature. If the temperature within the area is maintained to within a maximum of $5^{o}F$ above the ambient temperature the resulting heat load is greater than the peak hourly internal heat load as extracted from ECUBE. This temperature, in the general storage area, is well within the design parameters given by EATG. The following equation was solved for the heat transfer calculations used in this evaluation and

justification of two air changes per hour.

$$Qf = 1.08\ CFM(\Delta T) \quad (25)$$

where:

Qf = Heat removed by the fans resulting from two air changes per hour

CFM = Two air changes per hour (for the 30 foot building this is approximately 1,306,800 cubic feet per minute)

ΔT = Difference between internal temperature and ambient temperature, $5^{o}F$

The number of fans required for each building height is determined from the following equation:

Number of fans = CFM required for two air changes/CFM per fan (26)

where:

CFM required for two air changes = volume of general storage area per building height X 2 air changes per hour divided by 60 minutes per hour

Boiler Selection. The ECUBE simulation indicated that no heating was required for any portion of the warehouse. Unfortunately, the simulation process failed to consider drafts or personnel discomfort near the perimeter walls. The winter design temperature for Norfolk, Virginia is $15^{o}F$. Summation of the transmission loads and infiltration loads resulted in the total perimeter heat to be provided by the selected boiler systems. The following equations used in these calculations are as follows:

$UA(\Delta T)$(transmission) + $1.08\ CFM(\Delta T)$(ventilation) = heat load (see "HVAC Loads" section for complete analysis)

Each of the boiler sets were designed with two equal units to meet the load. A third, equal size, unit was added for backup. Table 105 indicates the total heat loads (transmission plus ventilation) and the selected boiler system horsepower.

Ducts and Piping. A detailed HVAC distribution system was not designed due to the nature of the input parameters available within the constraints of a design concept study.

TABLE 105

BOILER SYSTEMS SELECTION

BLDG HEIGHT (FT)	TOTAL HEAT LOAD (MBTUH)	SELECTED BOILER SYSTEM (HP)
30	2,885	3 @ 50
40	3,550	3 @ 65
50	4,214	3 @ 65
60	4,878	3 @ 75

Sample Design, 30 Foot Building. The following design is for the selected system of the 30 foot building.

Chillers:

2-525 ton and 2-950 ton Hermetic units

Pumps:

Condenser pumps - 2 @ 1538GPM @ 20.5 ft heat for the 525 ton chillers and 2 @ 2774GPM 22.0 ft heat for the 950 ton chillers

Evaporator pumps - 2 @ 1260 GPM @ 19.5 ft heat for the 525 ton chillers and 2 @ 2280GPM @ 21.85 ft heat for the 950 ton chillers

Total condenser water flow = (2 X 1538) + (2 X 2774) + 500 = 9124GPM

Cooling tower pumps = 2 @ (9124/2) = 2 @ 4562GPM @ 50 ft head

Total evaporator water flow = (2 X 1260) + (2 X 2280) = 7080GPM

Primary supply pumps = 4 @ (7080/3) = 4 @ 2360GPM @ 60 ft head

Cooling tower:

2 cells @ 5000 (these are the standard units above 4562GPM)

Air handling units:

Operating area, 12-36,000 CFM, 120 ton units

Mechanized area, 8-50,000 CFM, 225 ton units

Fans:

General storage area, 131-10,000 CFM fans

Boilers:

3 @ 40 HP

Commercial Power Systems

This section deals with the costs of the components of purchased power (electric) chiller systems. A brief development of what is meant by emergency power and standby (backup) power is presented. In addition, the design procedure used for analyzing a purchased power chiller system is presented. The costs for the selected purchased power chiller system for each building height is also presented in tables and a summary cost table for each building height is entered at the end of this section. Further design and cost data are entered in Appendix E-8 which indicate all purchased power chiller systems analyzed.

Electrical Systems Cost. An emergency power and a standby power system are desired by EATG to support this facility if commercial power is the prime source of power. An uninterruptible power system (UPS) is required for the computer load, regardless of whether the prime source of power is from commercial utility company or from a total energy system.

Emergency power systems may be defined as sources of electric power applied automatically to critical loads upon loss of the prime power. Critical loads are those loads that affect the health and safety of personnel plus those loads whose loss result in equipment or product damage (Woods, 1974:197). The critical load for this facility was assumed to include the emergency lighting load only. If a commercial power outage should occur, emergency lighting is required for safe exit and to facilitate starting and switching standby generators.

Emergency lighting circuits are separate from the primary distribution system section of this report. One generator of the standby power system is switched automatically into the emergency lighting circuits as soon as

a commercial power outage occurs.

A standby power system may be defined as a reserve source of electrical power arranged into a system to supply reliable power to loads at the proper time upon the loss of the prime source of power (Woods, 1974: 197). Off-line engine driven generators provide this standby capability. They can be started and switched into the primary distribution system at the primary substation.

The capacity of the standby power system is a function of the required loads. Tables 106 through 109 show the resultant loads required to be supported by the standby system for the 30, 40, 50, and 60 foot warehouses. These loads were developed by taking the normal productivity level and dividing it over a 24 hour workday. This resulted in a 40 percent productivity level. Electric load reduction factors were calculated to model this level of activity. The capital cost of the standby generators and associated control equipment are tabulated in Table 110. The equipment selection was based on the cost factors in the "Generator Units" section of this report.

The UPS is a system designed to provide power during all periods wherein the prime source of power is outside acceptable limits without causing disruption of the flow of acceptable power to the load (Woods, 1974:197). A typical UPS includes inverters, batteries and battery chargers. The capital cost of such a system sized to handle the computer load of this facility is approximately $93,400 (Lorain, 1975).

Commercial power enters a facility through the service equipment located at the primary substation. The service equipment usually includes fuses; circuit breakers; voltage, frequency, and power meters; and other

TABLE 106

LOADS REQUIRED TO BE SUPPORTED BY STANDBY GENERATORS

FOR 30 FOOT BUILDING

AREAS	CONNECTED LOAD (KW)	REDUCTION FACTOR	STANDBY LOAD (KW)
Operating			
Lights	400.	1.0	400.
Mat Handling	1419.	.3	425.7
Fans	222.	.75	166.5
Mechanized			
Lights	143	1.0	143.
Mat Handling	3774.	.3	1132.2
Fans	636.	.75	477.
General Storage			
Lights	429.	1.0	429.
Mat Handling	714.	.3	214.2
Fans	137.	.75	102.6
Mechanical Equipment			
Total	1650.	.75	1237.5
Building Total			4728.

TABLE 107

LOADS REQUIRED TO BE SUPPORTED BY STANDBY GENERATORS

FOR 40 FOOT BUILDING

AREAS	CONNECTED LOAD (KW)	REDUCTION FACTOR	STANDBY LOAD (KW)
Operating			
Lights	400.	1.0	400.
Mat Handling	1419.	.3	425.7
Fans	222.	.75	166.5
Mechanized			
Lights	154.5	1.0	154.5
Mat Handling	2923.2	.3	877.
Fans	357.3	.75	268.
General Storage			
Lights	496.4	1.0	496.4
Mat Handling	857.9	.3	257.4
Fans	182.	.75	136.5
Mechanical Equipment			
Total	1600.	.75	1200.
Building Total			4382.

TABLE 108

LOADS REQUIRED TO BE SUPPORTED BY STANDBY GENERATORS

FOR 50 FOOT BUILDING

AREAS	CONNECTED LOAD (KW)	REDUCTION FACTOR	STANDBY LOAD (KW)
Operating			
Lights	400.	1.0	400.
Mat Handling	1419.	.3	425.7
Fans	222.	.75	166.5
Mechanized			
Lights	165.4	1.0	165.4
Mat Handling	2450.7	.3	735.2
Fans	153.0	.75	115.
General Storage			
Lights	496.4	1.0	496.4
Mat Handling	1070.0	.3	321.0
Fans	228.0	.75	171.0
Mechanical Equipment			
Total	1500.	.75	1125.
Building Total			4121.2

TABLE 109

LOADS REQUIRED TO BE SUPPORTED BY STANDBY GENERATORS

FOR 60 FOOT BUILDING

AREAS	CONNECTED LOAD (KW)	REDUCTION FACTOR	STANDBY LOAD (KW)
Operating			
Lights	400.	1.0	400.
Mat Handling	1419.	.3	425.7
Fans	222.	.75	165.5
Mechanized			
Lights	162.6	1.0	162.6
Mat Handling	2072.7	.3	622.0
Fans	60.0	.75	45.0
General Storage			
Lights	450.9	1.0	450.9
Mat Handling	1212.8	.3	364.0
Fans	274.0	.75	205.5
Mechanical Equipment			
Total	1425.0	.75	1069.
Building Total			3911.2

TABLE 110

COST DATA FOR STANDBY GENERATORS

BUILDING (FT)	EQUIPMENT	UNIT COST	TOTAL COST
30	5 Each 1010 KW Diesel Generator W/O Waste Heat Reclaim	$174,502.60	$872,513
40	5 Each 1010 KW Diesel Generator W/O Waste Heat Reclaim	$174,502.60	$872,513
50	5 Each 1010 KW Diesel Generator W/O Waste Heat Reclaim	$174,502.60	$872,513
60	4 Each 1010 KW Diesel Generator W/O Waste Heat Reclaim	$174,502.60	$698,010

accessories. It controls and monitors the commercial power used by this facility. The capital cost of the service equipment for this facility is approximately $35,800 (Craftsman, 1973).

Electric Chiller Systems. To adequately analyze electric centrifugal chillers and their respective capital, maintenance, and energy costs four systems as outlined in the "HVAC System Design" section were analyzed for each building height. Each system was designed to provide the required cooling for the particular building height as developed in the "HVAC Energy Requirements" section. Both hermetic chillers and open chillers were investigated (see "Chiller Units" section). The number of chillers required and the tonnage provided by each is the same for either hermetic or open chillers. The primary reasons for considering both chiller types is to examine how energy costs and capital costs differ. The annual maintenance costs are the same for both types. In addition, system pump and cooling tower (see "HVAC System Design" section) requirements were equivalent. The costs associated with the building equipment (boiler system, air handling units, ducts and piping, and fans) plus the backup power, emergency batteries, and the mechanical room substation costs are added to each chiller type for each system. The 16 electric chiller systems for all four building heights are as follows:

Hermetic Chiller/Open Chiller System *

30 Foot Building

System Number	Primary Units	Backup Units
1	1-400 Ton 2-725 Ton	1-725 Ton
2	2-400 Ton 1-1050 Ton	1-1050 Ton

System Number	Primary Units	Backup Units
3	2-950 Ton	1-950 Ton
4	3-620 Ton	1-620 Ton

* Common unit sizes were used for both hermetic and open chiller systems.

40 Foot Building

System Number	Primary Units	Backup Units
1	1-400 Ton 2-725 Ton	1-725 Ton
2	2-400 Ton 1-1050 Ton	1-1050 Ton
3	2-950 Ton	1-950 Ton
4	3-620 Ton	1-620 Ton

50 Foot Building

System Number	Primary Units	Backup Units
1	1-400 Ton 2-675 Ton	1-675 Ton
2	2-400 Ton 1-950 Ton	1-950 Ton
3	2-950 Ton	1-950 Ton
4	3-575 Ton	1-575 Ton

60 Foot Building

System Number	Primary Units	Backup Units
1	1-350 Ton 2-675 Ton	1-675 Ton

System Number	Primary Units	Backup Units
2	2-400 Ton 1-950 Ton	1-950 Ton
3	2-850 Ton	1-850 Ton
4	3-575 Ton	1-575 Ton

Cost Data for Selected Systems. Included in this part is a brief development of the cost data for the best purchased power (electric chiller) system for the 30 foot building. In addition, tables of cost data for the best purchased power system for each building height are presented at the end of this section and a summary of capital, maintenance, energy, and annual costs are also tabulated. This particular system was chosen to demonstrate the design technique because the 30 foot building has the largest cooling load. This system is representative of the other best electric chiller systems and the development presented is identical to the procedures followed throughout. Refer to Appendix E-8 for the complete cost data of purchased power chiller systems.

Costs for the 30 foot building were developed in the following manner:

1. Select chiller units.

   Hermetic chillers: 2-525 ton and 2-950 ton

   Compute capital cost:

   Number of chiller units X capital cost per unit

   Compute maintenance cost:

   Number of operating hours X cost per operating hour

   Compute energy cost:

   KWH requirements derived from ECUBE X inflated electricity cost ($.0441/KWH)

2. Select pumps.

   Compute capital cost:

   14 pumps X capital cost per pump

   Compute maintenance cost:

   14 pumps X $55 per pump

3. Select cooling tower.

   Compute capital cost:

   1 unit(2 cells) X cost per unit

   Compute maintenance cost:

   2 cells X $1000 per cell

4. Select boiler system.

   Compute capital cost:

   2 boilers X cost per boiler

   Compute maintenance cost:

   Operating hours and maintenance are negligible due to infrequency of operation resulting from being located at a southern latitude

5. Select air handling units.

   Compute capital cost:

   Number of AHU X cost per AHU

   Compute maintenance cost:

   Number of AHU X annual cost per AHU

6. Select ducts and piping.

   Compute capital cost (ducts):

   Sum of capital costs of chillers and AHU X 15%

   Compute capital cost (piping):

Sum of capital costs of chillers and AHU X 25%

Compute maintenance cost:

Assumed to be negligible

7. Select fans.

Compute capital cost:

Number of fans X cost per fan

Compute maintenance cost:

Number of fans X $30 per fan

The electrical system costs were discussed earlier in this section and these costs are added to the mechanical equipment costs to arrive at the total equipment cost.

In addition to the electrical and mechanical equipment costs the building electricity costs must be included to accurately compare each purchased power system with total energy systems developed in the next section of this report.

The electrical consumption for the chiller units and associated system pumps is computed by the ECUBE simulation. Actual costs for the selected 30 foot building system are listed in Table 111. Tables 112, 113, and 114 give the corresponding data on the selected systems for the other building heights. Appendix E-12 contains the energy consumption tables for all systems considered.

TABLE 111

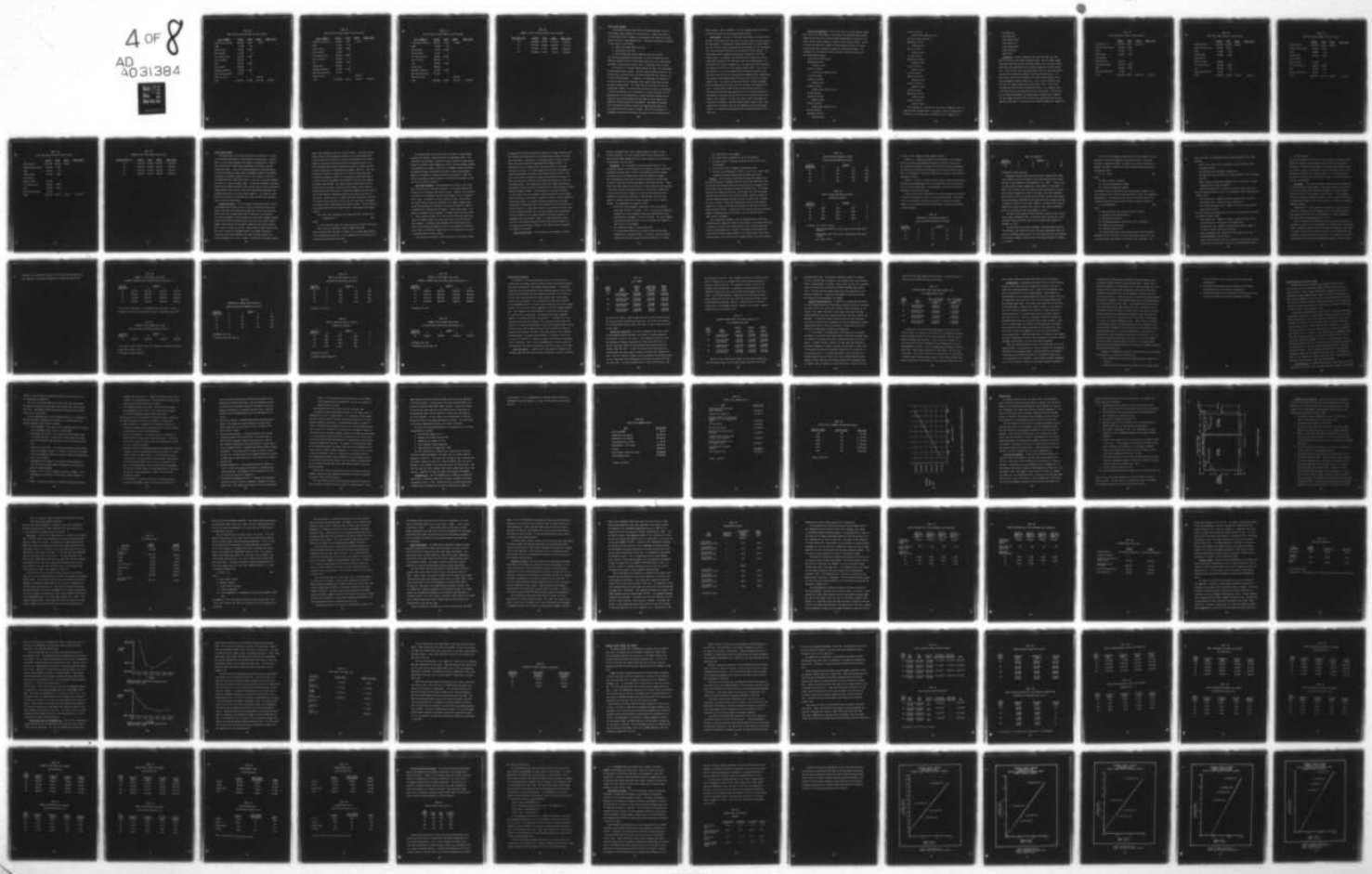
BEST ELECTRIC CHILLER SYSTEM, 30 FOOT BUILDING

SYST 2 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-525 Ton & 2-950 Ton	275,600	9,400	81,268	
Pumps	60,849	770		
Cooling Tower	86,000	2,000		
Boiler System	18,513	0		
Air Handling Units	320,334	10,640		
Ducts & Piping	238,374	0		
Fans	236,848	3,930		
Backup Power	872,513	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Bldg Elec Costs			1,018,989	
Total	2,309,886	29,385	1,100,257	1,384,122

AD-A031 384 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 13/2
A GENERAL WAREHOUSE MODULE CONCEPTUAL DESIGN AND COST ANALYSIS.--ETC(U)
SEP 76 R T ALEXANDER, T J CARMICHAEL

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4 OF 8
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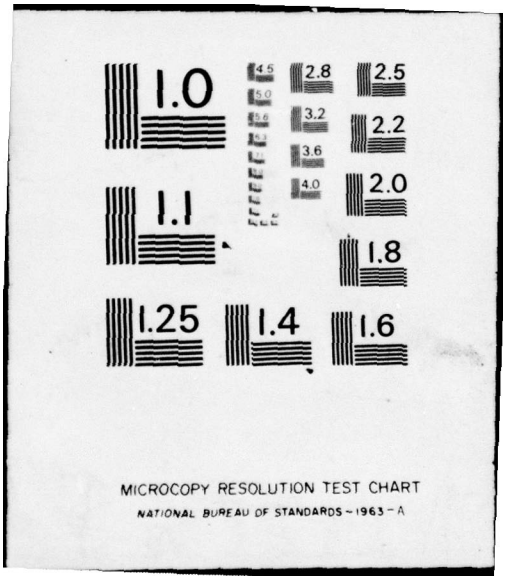

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963 - A

TABLE 112

BEST ELECTRIC CHILLER SYSTEM, 40 FOOT BUILDING

SYST 1 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
1-400 Ton & 3-725 Ton	254,700	8,613	74,043	
Pumps	57,389	770		
Cooling Tower	76,000	2,000		
Boiler System	22,236	0		
Air Handling Units	276,348	9,360		
Ducts & Piping	224,259	0		
Fans	243,430	3,300		
Backup Power	869,400	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Bldg Elec Costs			933,703	
Total	2,224,617	26,688	1,007,746	1,279,520

TABLE 113

BEST ELECTRIC CHILLER SYSTEM, 50 FOOT BUILDING

SYST 2 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-950 Ton	265,200	7,720	58,707	
Pumps	58,316	770		
Cooling Tower	76,000	2,000		
Boiler System	22,236	0		
Air Handling Units	287,438	10,640		
Ducts & Piping	221,055	0		
Fans	277,950	3,270		
Backup Power	869,400	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Bldg Elec Costs			905,334	
Total	2,278,450	27,049	964,041	1,242,103

TABLE 114

BEST ELECTRIC CHILLER SYSTEM, 60 FOOT BUILDING

SYST 2 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-950 Ton	265,200	7,029	53,089	
Pumps	58,558	770		
Cooling Tower	77,000	2,000		
Boiler System	30,335	0		
Air Handling Units	314,800	11,920		
Ducts & Piping	232,000	0		
Fans	334,050	3,930		
Backup Power	698,010	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Bldg Elec Costs			869,158	
Total	2,210,808	28,294	922,247	1,194,106

TABLE 115

SUMMARY OF COSTS FOR BEST ELECTRIC CHILLER SYSTEMS

BLDG HEIGHT (FT)	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
30	2,309,886	29,385	1,100,257	1,384,122
40	2,254,217	26,688	1,002,693	1,277,728
50	2,278,450	27,049	964,041	1,242,103
60	2,210,808	28,294	922,247	1,194,106

Total Energy Systems

The concept of total energy differs from purchased power in that a total energy system produces its own electricity. Number two diesel oil is the primary source of energy for the generators but other fuel sources may be utilized in some generator units. The three prime movers considered in this report are as follows:

1. Small, high speed diesel units (D)
2. Gas turbine units (GT)
3. Gas turbine/steam turbine combined cycle units (GT/ST)

All units were evaluated using #2 diesel oil since this particular fuel grade was acceptable within the operating limitations of all prime movers considered (see discussion of other fuels in "Generator Units" section).

The evaluation of the total energy systems was made in the same manner as the purchased power systems. The total energy systems provided for the cooling loads of the operating area and the mechanized area, 20 acres, for all four building heights. In addition, to investigate the potential of cooling the entire 50 acre warehouse total energy systems were designed for each building height. This latter design was not done for the purchased power systems. Air conditioning the entire 50 acres was considered a realistic design due to the availability of excess waste heat from the generator units as an energy source. Seven prime mover systems were designed for each building height with the number of units based on the respective building electricity requirements. The number of generator units was selected to meet the electricity demand and one backup unit was provided for the GT and GT/ST systems. Due to the differences in recommended maintenance scheduling, two backup units are provided for the

diesel systems. Refer to Appendix E-9 for a complete tabular listing of all 20 acre and 50 acre total energy systems analyzed.

Cost Analysis. The costs of the ducts and piping, air handling units, and fans are the same as for the electric chiller systems for the respective building heights. The mechanical room substation costs are significantly less for the total energy systems due to the elimination of the requirement for a large step-down transformer for the electric chiller systems. No backup power units or emergency batteries are required for the total energy systems. In addition, the building boilers required for the purchased power systems are not required for the total energy systems. As indicated by the tables in Appendix E-9 , the waste heat boiler costs were not included in the GT and D total energy systems' costs. This is due to the relatively low cost associated with the required waste heat boilers when amoritized over 25 years and because the purchased power systems were less expensive even without adding the boiler costs to the total energy systems' costs. The GT/ST units have the boilers included as packaged units and therefore, the boiler costs are included in the generator unit costs. The best GT/ST system for the 30 foot building, 20 acres, is approximately 18 percent more expensive than the best diesel system but the addition of the waste heat boiler cost to the diesels brings the two systems closer together. Of course the capital costs of the generator units must be included in the total energy systems' overall costs. Upon inspection of the capital costs for the components of the total energy systems it is obvious that the generator units comprise the bulk of the total cost.

Chillers and Generators. The chillers used in the total energy systems were sized in the same manner as those used in the purchased power systems. Absorption chillers were sized (see "HVAC Systems Design" section) for the diesel and gas turbine generator systems for each building height. Electric chillers were sized (see "Commercial Power Systems" section) for the gas turbine/steam turbine generator systems for each building height. The following list indicates the chillers used for both the 20 acre and 50 acre total energy systems.

30 foot building (20 acres)

Absorption chillers

3-1148 ton units

Electric chillers

2-525 ton and 2-950 ton units

40 foot building

Absorption chillers

3-960 ton units

Electric chillers

1-400 ton and 3-725 ton units

50 foot building

Absorption chillers

3-908 ton units

Electric chillers

2-400 ton and 2-950 ton units

60 foot building

Absorption chillers

3-908 ton units

Electric chillers

2-400 ton and 2-950 ton units

30 foot building (50 acres)

Absorption chillers

4-960 ton units

Electric chillers

4-950 ton units

40 foot building

Absorption chillers

4-908 ton units

Electric chillers

4-850 ton units

50 foot building

Absorption chillers

3-908 ton units

Electric chillers

4-850 ton units

60 foot building

Absorption chillers

3-908 ton units

Electric chillers

4-850 ton units

The following list indicates the seven types of generator units analyzed for each building height. The number of each unit specified is included in the tabulated cost calculations found in Appendix E-9.

DDA 3000 KW GT

Solar 800 KW GT

Solar 1200 KW GT/ST

Solar 2500 KW GT

Solar 3750 KW GT/ST

Cummins 690 KW D

DDA 795 KW D

Conclusions. The best system for each building height was a DDA (Detroit Diesel Allison) diesel generator system. The two diesel systems investigated (DDA 795 KW units and Cummins 690 KW units) for each building height were very comparable but the slightly larger unit was more economical. In the future, larger high speed diesel units will be on the market and these units should be included in any future design analysis. The GT/ST units should also be included in any future design analysis due to the developmental nature of these units. Their initial evaluation shows that they are closely competitive with the diesel units. The GT units are expensive initially and the thermal efficiency is not adequate unless a way can be found to use the waste heat more productively. Further analysis of energy requirements to include process equipment loads, domestic hot water usage, and other similar energy uses, where waste heat could be applied, could result in gas turbine units becoming economically competitive.

TABLE 116

BEST TOTAL ENERGY SYSTEM, 30 FOOT BUILDING

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
12-DDA 795 KW D	2,094,030	127,272	1,024,731	
3-1148 Ton AB Chillers	339,600	12,454		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		
Waste Boilers				
Ducts & Piping	238,374	0		
Air Handling Units	320,334	10,640		
Fans	236,848	3,930		
Mech Room Substation	45,414	0		
Total	3,507,150	158,011	1,024,731	1,569,125

TABLE 117

BEST TOTAL ENERGY SYSTEM 40 FOOT BUILDING

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
10-DDA 795 KW D	1,745,025	115,258	923,806	
3-960 Ton AB Chillers	290,700	11,576		
Pumps	66,384	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Ducts & Piping	224,259	0		
Air Handling Units	276,348	9,360		
Fans	243,430	3,300		
Mech Room Substation	45,414	0		
Total	3,031,560	143,209	923,806	1,401,002

TABLE 118

BEST TOTAL ENERGY SYSTEM, 50 FOOT BUILDING

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
10-DDA 795 KW D	1,745,025	110,083	880,587	
3-908 Ton AB Chillers	278,400	10,102		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Ducts & Piping	221,055	0		
Air Handling Units	287,438	10,640		
Fans	277,950	3,270		
Mech Room Substation	45,414	0		
Total	3,060,231	137,810	880,587	1,355,543

TABLE 119

BEST TOTAL ENERGY SYSTEM, 60 FOOT BUILDING

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
9-DDA 795 KW D	1,570,523	104,565	834,933	
3-908 Ton AB Chillers	278,400	9,441		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Ducts & Piping	232,000	0		
Air Handling Units	314,800	11,920		
Fans	334,050	3,930		
Mech Room Substation	45,414	0		
Total	2,980,136	133,571	834,933	1,297,610

TABLE 120

SUMMARY OF BEST TOTAL ENERGY SYSTEM COSTS

BUILDING HEIGHT (FT)	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
30	3,507,150	158,011	1,024,731	1,569,125
40	3,031,560	143,209	923,806	1,401,002
50	3,060,231	137,810	880,587	1,355,543
60	2,980,136	133,571	834,933	1,297,610

Solar Energy Systems

The feasibility of utilizing solar energy to provide all, or a part of, the energy requirements of the warehouse was investigated. Improvements in solar energy equipment and advances in manufacturers' research have led many public and private organizations to seriously consider using solar energy. Due to the increased emphasis on conserving energy and securing alternate energy sources, government projects are currently encouraged to thoroughly analyze the use of solar energy in lieu of or in conjunction with, conventional fuels to cool, heat, and provide domestic hot water to a facility (Lardis, 1976). The National Aeronautics and Space Administration (NASA) (Pendleton, 1976) and the Naval Facilities Engineering Command (NFEC) (Beck and Field, 1976) have independently researched solar equipment application for use by Federal agencies. This study will compare the two methods of collecting solar energy that are most frequently used in industrial application.

Tracking Collectors. The first method incorporates automatic tracking equipment that focuses the sun's radiation (insolation) onto an absorber plate where the concentrated energy heats a water and anti-freeze mixture that flows through copper tubes at the base of the collector. The tracking equipment is activated when one side of the V-shaped collector receives more insolation than the other side and a small electric motor, capable of driving up to 30 collectors, moves the face of the collector until it points directly to the sun. One collector is made of two silicon cells set on a base at a 60 degree angle to one another covered by a curved lens specifically designed to transmit maximum radiation (E.I. du Pont de Nemours & Co., (Inc.), 1976). The absorbers are small, parallel

copper tubes attached to the base of the collectors. The water and anti-freeze solution flows through the absorbers and the concentrated solar radiation heats the fluid before it enters the absorption chiller units. Copper is considered to be the best metal for absorbers because it exhibits excellent heat transfer characteristics and is the most corrosion resistant common metal (Libbey-Owens-Ford Company, 1976:1-2). Steel and aluminum are usually less expensive but a system of electrostatically dip-painting (Honeywell, 1976) will be required to protect the metal in a highly corrosive environment like the Norfolk, Virginia area (Fontana and Greene, 1967:265:268). For copper tubing, ethylene glycol acts as an excellent anti-freeze, as long as the anti-freeze solution does not exceed 60 percent ethylene glycol, and provides adequate corrosion control. The solution should be checked periodically by testing pH and ion concentration. Ethylene glycol is slightly more dense than water; therefore, the ethylene glycol and water solution holds less heat than a corresponding amount of water (Libbey-Owens-Ford Company, 1976:5). The heat content can be determined from the following equation (Libbey-Owens-Ford Company, 1976:5).

BTUH = GPM X 500 X (entering fluid temperature minus leaving fluid temperature) X F (27)

where:

F is the correction factor for weight and specific heat of the glycol-water solution as defined in tables (ASHRAE, 1972a:282).

When dissimilar metals may come in contact, as in framing support members for the collector housing units, it is recommended that insulation joints be used to prevent galvanic corrosion.

The average annual efficiency of these collectors is approximately 60 percent for Norfolk, Virginia (Northrup, Incorporated, 1976). This relatively high efficiency in relation to other collector systems greatly reduces the required square footage of collector area and theregy provides a considerable cost savings. The prices of automatic tracking collectors are generally higher than either flat plate or vacuum tube collectors. However, the reduction in required collector area results in fewer collectors to purchase, install, maintain, and provide miscellaneous service over the life of the collectors.

Flat Plate Collectors. The second method considered in this study deals with the use of flat plate collectors. As the name indicates the collectors are stationary, flat pieces of glass. Normally, the collectors are erected on a reasonably flat roof and the angle of tilt is adjusted twice a year. For winter use, lower insolation levels, the collectors are usually tilted up from the horizontal, the number of degrees equal to the latitude where the collectors are being used (Norfolk, Virginia = 37 degrees north latitude) plus 10 degrees. Summer usage assumes a tilt angle of 37 degrees minus 10 degrees = 27 degrees (Beck and Field, 1976: 7). These respective angles of tilt are not fixed values but may be adjusted ±10 degrees without any significant effect on the efficiency of the collectors. Collectors should normally be oriented facing to the south in the northern hemisphere, but due to the probability of morning fog or haze in the Norfolk, Virginia area up to 15 degrees west of south is advisable (Beck and Field, 1976:5).

The flat plate collectors in this study consist of two cover plates

of tempered 1/8 inch thick glazed glass above an all copper absorber plate. The absorber base plate consists of an embossed copper sheet with copper tubes attached by a solder bond. This design reduces corrosion and provides long term reliability (Libbey-Owens-Ford Company, 1976:2). As explained earlier, an ethylene glycol and water solution is the heat absorbing fluid used. This liquid system has a parallel flow pattern of copper tubing designed to provide uniform flow through all tubes. Moisture relief venting is provided to prevent the accumulation of water between the glass cover plates and from between the bottom cover plate and the absorber plate. This improves the efficiency, reduces the necessary maintenance, and will inevitably prolong the life of the collectors (Libbey-Owens-Ford Company, 1976:2). The efficiency of flat plate collectors is almost always less than automatic tracking collectors, and an average annual efficiency of 50 percent is assumed for Norfolk, Virginia (Northrup, Incorporated, 1976). This lower efficiency coupled with the assumed coefficient of performance (COP) of the absorption chillers of 0.60 (York 1975a:3) results in a significant increase in the required collector area. The real difference between the flat plate collectors and the automatic tracking collectors is the square footage of collectors necessary to adequately cool the warehouse. There is a large differential between the cost of the tracking collectors and the flat plate collectors, but all other costs are directly related to the installed square footage of the respective collectors.

Warehouse Application. The roof area of this warehouse is large

enough to accommodate the square footage required by either of these collection methods. The total cooling load of each building height is taken from the ECUBE computer printout of zone summation for the operating and mechanized areas (20 acres).

Assumptions. For the purpose of simplifying the analysis of utilizing solar energy to cool 20 acres of the warehouse, several significant assumptions have been made in favor of solar energy collection methods. The premise was to investigate solar collection methods and compare their representative costs with the costs of combination systems (solar collectors, absorption chillers and electric centrifugal chillers). These results were then compared with the costs of total electric chiller systems. If any solar collector system had proved to be economically competitive with the electric chiller system for a given building height the basic assumptions, giving every advantage to solar systems, would have been amended to further scrutinize the actual economics of solar collection systems. The assumptions are listed as follows:

1. The life of solar equipment, absorption chillers, and electric centrifugal chillers is 25 years. This is a particularly beneficial assumption for solar equipment because most manufacturers do not guarantee their equipment in excess of 15 years. The solar industry is relatively young and there is very little practical industrial application of its equipment.
2. The average wind speed is ten miles per hour.
3. All solar energy available will be used to lower the building temperature to a minimum of 65°F. In addition, when the internal building cooling load increases the stored material will release

the "cooling BTU's" upon demand.

4. No salvage value is expected for any of the equipment.
5. No major overhaul is required during the 25 year life of any of the equipment.
6. No escalation rate is figured for maintenance costs.
7. The part load performance of electric chillers has a nearly linear relationship between percent load and percent fuel input.

Analysis. The technique of analyzing the respective methods of collecting solar energy is dependent upon the results from ECUBE (AGA, 1975). The cooling load for each building was extracted from the computer printout and these loads determined the required collector areas. The tonnage loads from the computer printout are significantly less than the tonnage loads derived from either solar collection method (Tables 121 and 122) because the computer program simulates 18 hours of cooling load, including two hours of prechill before the workday begins, and the solar methods assume only six hours of useable sun radiation for each day of the year (Beck and Field, 1976:9). Prorating the total cooling load over the greater number of operating hours for the electric chiller systems results in lower tonnage requirements.

Four systems were designed to cool the operating area and the mechanized area which comprise 20 acres of the warehouse. Each system described is capable of providing the cooling load for each building and only the sizes of the equipment vary. System 1 is designed to be the prime competition for the three systems because it is a total electric centrifugal chiller system. The electric chiller systems and their costs are discussed

TABLE 121

TONS OF COOLING PROVIDED BY SOLAR

COLLECTORS AND ABSORPTION CHILLERS

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	0	975	678	2346
40	0	753	491	2073
50	0	671	428	1934
60	0	601	373	1817

TABLE 122

TONS OF COOLING PROVIDED BY ELECTRIC

CENTRIFUGAL CHILLERS

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	1938	963	1260	0
40	1791	1038	1300	0
50	1722	1051	1294	0
60	1667	1066	1294	0

** System 1 All electric cooling

2 Approximately 60% solar cooling, approximately 40% electric cooling

3 Approximately 40% solar cooling, approximately 60% electric cooling

4 All solar cooling

in detail in the "Commercial Power Systems" section.

System 2 is a combination system of solar collectors and absorption chillers providing approximately 63 percent of the total cooling load for the 30 foot building, 57 percent for the 40 foot building, 55 percent for the 50 foot building, and 53 percent for the 60 foot building (Table 123). The remainder of the load is picked up by a system of three electric centrifugal chillers.

System 3 is similar to System 2 but the solar collectors and absorption chillers provide approximately 16 to 17 percent less of the total cooling load for each building height. The same number of electric chillers are provided for each building height.

System 4 provides for 100 percent of the total cooling load with solar collectors and absorption chillers for each building height. No electric chillers are provided, therefore this system will require the largest number of solar collectors for both the automatic tracking and flat plate collector methods.

TABLE 123

PERCENTAGE OF COOLING LOAD PROVIDED BY

SOLAR COLLECTORS AND ABSORPTION CHILLERS

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	0	63	47	100
40	0	57	40	100
50	0	55	38	100

TABLE 123 CONTINUED

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
60	0	53	36	100

** Reference footnote page 279

Absorption chillers operate most efficiently at approximately 250°F (York, 1975a:3) but solar collectors cannot consistently provide a water solution at that temperature (PPG Industries, Inc., 1976). A normal range of solar collector output temperatures, either method, is from 180°F to 200°F, and in order to give solar energy systems an advantage an average water solution temperature of 200°F was assumed. With this temperature the absorption chillers are unable to provide their maximum rated tonnage (Duffie and Beckman, 1974:316) and the required chiller tonnages have been increased by a factor of 1.82 (York, 1975a:3). The costs of the required absorption chillers include the total capital costs, annual maintenance costs, and installation costs for Systems 2, 3, and 4.

The costs of the required electric chillers include the total capital costs, annual maintenance costs, installation costs, starting unit costs, and annual electricity costs with a fuel inflation factor applied for Systems 1, 2, and 3.

The total costs of the solar equipment include the capital costs of the collectors, the installation costs, the annual maintenance costs, the costs of providing ethylene glycol as an antifreeze and corrosion inhibitor, and the costs of pumps, piping and other associated equipment for Systems 2, 3, and 4.

The data for calculating the required area of the automatic tracking collectors is taken from Northrup, Incorporated technical literature (Northrup, Incorporated, 1976). The mean solar collector temperature is assumed to be 190°F as determined from the following equation (Northrup, Incorporated, 1976):

$$TM = (TI + TE)/2 \quad (28)$$

where:

TM = Mean collector temperature

TI = Fluid inlet temperature (180°F)

TE = Fluid exit temperature (200°F)

The technical data for determining the required square footage of flat plate collectors was provided by the NFEC technical report and independent manufacturers. The energy available from the flat plate collectors is calculated from the following equation (Barber and Watson, 1975:C-2):

$$Q = I(E)(PA)(DM)(CA) \quad (29)$$

where:

Q = Energy available from collectors (BTU/sq ft-month)

I = Insolation value (BTU/sq ft-day)

E = Efficiency of collector

PA = Average percentage of sunshine per day for each month

DM = Number of days per month

CA = Collector area (sq ft)

The total system costs for each building height were calculated by summing the total solar costs, the total absorption chiller costs, and the total electric centrifugal chiller costs, where applicable. The

total solar costs are represented by the following analysis (Beck, 1976: 33-34,44).

Capital cost = Cost sq ft of collectors X square footage of solar collectors required

Installation cost = 20 percent X capital cost

Ethylene glycol cost = $2.00/sq ft X square footage of solar collectors required

Pumps, piping, and associated equipment costs = $1.00/sq ft X square footage of solar collectors required

Annual maintenance cost = 1 percent X sum of all other solar costs

The total absorption chiller costs are represented by the following analysis (Albitz, 1976).

Total capital cost = Number of chillers X capital cost per chiller

Installation cost = 10 percent X total capital cost

Total annual maintenance cost = Number of chillers X annual maintenance cost per chiller

The total electric centrifugal chiller costs are represented by the following analysis (Albitz, 1976).

Total capital cost = Number of chillers X capital cost per chiller

Installation cost = 10 percent X total capital cost

Starting units cost = Number of starting units (same as number of chillers) X capital cost per starting unit

Annual maintenance cost = Number of chillers minus one chiller X annual maintenance cost per chiller

Annual electricity costs with fuel inflation factor applied = cost of electricity per million BTU X millions of BTU provided by electric

chillers annually

All costs are presented in their final form as annual costs (Grant, 1970: 66-84) and a summary of each systems' cost for each building height is presented in Table 124 for the automatic tracking collector method. Table 125 presents a summary of the annual costs for each system of the 30 foot building for the flat plate collector method. Due to the obvious prohibitive costs of the flat plate collector method, only the 30 foot building costs are presented.

Conclusions. Solar energy collection systems are not cost effective for this relatively large warehouse. Due to the economics of large electric chiller systems and the additional competition from total energy systems the use of solar collectors is not feasible. If the warehouse ever requires heating or domestic hot water, solar collectors may prove to be economically competitive due to the significant increase in conventional equipment required.

Manufacturers of solar equipment are continuing to improve the efficiency and reliability of their products and it is conceivable that as the industry grows the prices of the equipment will become competitive with conventional energy equipment (G.E., 1976).

Due to a request by the EATG the same solar collection methods were analyzed for possible use in the Oklahoma City, Oklahoma area. The average monthly insolation values for the south central and southwest United States are greater than those for the Norfolk area and it was assumed that solar collectors could possibly have more potential. The larger cooling load in the Oklahoma City area more than overcomes the greater insolation values.

Therefore, as in the Norfolk analysis, solar collection systems are not cost effective. The tables containing the Oklahoma City data follow.

TABLE 124

SUMMARY OF TOTAL ANNUAL COSTS USING

AUTOMATIC TRACKING SOLAR COLLECTORS COSTING $18.00/SQ FT *

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	$121,031	$257,383	$224,326	$413,392
40	$108,924	$199,085	$181,099	$371,125
50	$ 95,644	$189,017	$168,498	$352,543
60	$ 89,335	$177,405	$159,201	$332,233

* This cost is referenced to a telephone conversation with L. Lincoln Eldredge, Executive Vice President of Northrup, Incorporated, May, 1976.

TABLE 125

SUMMARY OF TOTAL ANNUAL COSTS USING

FLAT PLATE SOLAR COLLECTORS COSTING $8.00/SQ FT *

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	$121,031	$391,228	$454,905	$754,355

* This cost is taken from the Naval Civil Engineering Laboratory Technical Report R835, January, 1976.

** Reference footnote page 279

TABLE 126

PERCENTAGE OF COOLING LOAD PROVIDED BY

SOLAR COLLECTORS AND ABSORPTION CHILLERS *

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	0	65	46	100
40	0	60	37	100
50	0	68	36	100
60	0	55	34	100

* Oklahoma City, Okla.

** Reference foot note page 279

TABLE 127

TONS OF COOLING PROVIDED BY SOLAR

COLLECTORS AND ABSORPTION CHILLERS *

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	0	1206	729	2820
40	0	980	518	2549
50	0	872	463	2411
60	0	780	415	2297

* Oklahoma City, Okla.

TABLE 128

TONS OF COOLING PROVIDED BY ELECTRIC

CENTRIFUGAL CHILLERS *

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	2625	1419	1896	0
40	2442	1462	1924	0
50	2278	1406	1815	0
60	2073	1293	1658	0

* Oklahoma City, Okla.

** Reference footnote page 279

TABLE 129

SUMMARY OF TOTAL ANNUAL COSTS USING

AUTOMATIC TRACKING SOLAR COLLECTORS COSTING $18.00/SQ FT *

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	$145,237	$277,389	$246,155	$476,320
40	$130,710	$244,752	$201,049	$435,381
50	$114,773	$277,910	$189,099	$414,312
60	$107,202	$213,444	$180,811	$398,216

* Oklahoma City, Okla.

TABLE 130

SUMMARY OF TOTAL ANNUAL COSTS USING

FLAT PLATE SOLAR COLLECTORS COSTING $8.00/SQ FT *

BUILDING HEIGHT (FT)	SYSTEM ** 1	2	3	4
30	$145,237	$459,932	$374,480	$733,230

* Oklahoma City, Okla.

** Reference footnote page 279

Energy System Selection

As presented in the preceding three sections of this report, purchased power, total energy, and solar energy systems were evaluated against the energy requirements of the proposed warehouse module. This section compares the pricing information for the purchased power and total energy systems and then selects the least expensive alternative as the basis for the cost data resulting from this design concept study. Solar energy systems are not presented in this section because they were eliminated in the preceeding section. The cost figures presented in the "Solar Energy Systems" section are not directly comparable to the cost figures presented here. Not included in the solar systems cost data were cooling towers, air handling units, backup power, and several other system components common to all systems evaluated in that section. In addition, the building energy costs were not included. This was done for simplification of analysis, as stated under assumptions in the "Solar Energy Systems" section, and none of the solar systems could realistically compete with the best purchased power system or the best total energy system for the respective building heights. Following system selection, an analysis of the sensitivity of this decision in relation to changes in working hours and energy costs is presented. Then a list of recommendations is given on possible considerations and further investigations outside the scope of this study.

Least Cost System. A summary of the least expensive system for the purchased power and total energy systems investigated is given in Table 131.

TABLE 131

COST SUMMARY

BLDG HEIGHT (FT)	TYPE SYSTEM	CAPITAL COSTS ($)	ENERGY AND MAINT. COSTS ($/YR)	ANNUAL COSTS ($/YR)
30	Purchased Power	2,309,886	1,129,642	1,384,122
	Total Energy	3,507,150	1,182,742	1,569,125
40	Purchased Power	2,224,617	1,034,434	1,279,520
	Total Energy	3,031,560	1,067,015	1,401,002
50	Purchased Power	2,278,450	991,090	1,242,103
	Total Energy	3,060,231	1,018,397	1,355,543
60	Purchased Power	2,210,808	950,541	1,194,106
	Total Energy	2,980,136	968,504	1,297,610

The annual cost values in Table 131 show that for all four building heights, the purchased power system had the lowest cost. This led to the selection of a purchased power energy system as the basis for cost estimates provided by this study.

Working Hour Sensitivity. An initial assumption, specified by EATG, was the workweek schedule outlined in the "Material Handling Equipment and Personnel" section of this report. This assumption specified a seven day workweek with weekdays having one full eight hour shift plus a 25 percent, eight hour night shift while weekends and holidays had one 25 percent, eight hour shift. To test the sensitivity of the selection of purchase power over total energy, a study of two other work schedules was made. The first schedule included a seven day workweek with weekdays having two full eight hour shifts and weekends and holidays having one full eight hour work shift. The second schedule had full work shifts 24 hours a day

for every day of the year. These schedules represent the predicted normal level of productivity, an increased level, and the maximum productivity available from the facility. This extension of hours is based on the assumption that the day shift is operating at maximum capacity and no additional productivity can be derived from adding manpower during day shifts. Using these schedules, a comparison at the selected purchased power system versus the least cost total energy system was made for each building height by computer simulation. Table 132 lists the resulting annual costs for the systems analyzed. Appendix E-10 includes a complete tabulation of unit and energy costs.

TABLE 132

PURCHASED POWER VERSUS TOTAL ENERGY ANNUAL COSTS

WITH INCREASED WORK HOURS

BLDG HEIGHT (FT)	TYPE SYSTEM	SCHEDULE 1 ($/YR)	SCHEDULE 2 ($/YR)	SCHEDULE 3 ($/YR)
30	Purchased Power	1,384,122	1,700,107	2,733,252
	Total Energy	1,569,125	1,887,074	2,929,646
40	Purchased Power	1,279,520	1,543,839	2,449,893
	Total Energy	1,401,002	1,693,877	2,597,781
50	Purchased Power	1,242,103	1,488,469	2,784,804
	Total Energy	1,355,543	1,638,529	2,494,231
60	Purchased Power	1,194,106	1,426,619	2,233,837
	Total Energy	1,297,610	1,571,042	2,381,391

Results of this investigation showed that the normal schedule one, the total energy annual costs are approximately ten percent more than

purchased power costs. The proportion remained constant for schedule two, the increased level of activity. For schedule three, the difference drops to approximately six percent. These results show that for reasonable levels of productivity, the decision to select purchased power remains valid. They also show that annual energy costs vary significantly with work hour scheduling. In addition, adjustments to the final cost data are required if these parameters are changed.

Energy Pricing Sensitivity. In addition to checking the sensitivity of the purchased power versus total energy systems with work hour variances, the sensitivity of the results with differing values of energy costs was checked. The largest contributor to the annual cost values for every system analyzed was the yearly energy consumption required to operate the equipment. To compute the annual costs during the system evaluations, a base price of electricity was assumed at $0.021 per kilowatt-hour; however, quotations on electric rates in the Norfolk, Virginia area varied from $0.021 per kilowatt-hour to $0.028 per kilowatt-hour.

In a like manner, an assumed value of $0.33 per gallon for number two diesel oil was used in the study; however, quotations on recent prices in the Norfolk, Virginia area varied from $0.28 per gallon to $0.34 per gallon. To reflect current inflation, the base rates were factored as outlined in Appendix E-1 using an assumed inflation rate for electricity of ten percent per year and an assumed inflation rate for diesel oil of six percent per year. To evaluate the effects on the study results of changed energy prices, the annual cost of the selected purchased power systems, and the least cost total energy systems were re-computed based on electric rates of $0.028 per kilowatt-hour and oil rates of $0.30 per

gallon using the same assumed inflation factors. Table 133 shows the annual costs resulting from these calculations.

TABLE 133

PURCHASED POWER VERSUS TOTAL ENERGY ANNUAL COSTS

WITH CHANGED ENERGY PRICES

BLDG HEIGHT (FT)	TYPE SYSTEM	ELEC = $0.021/KWH OIL = $0.33/GAL ($/YR)	ELEC = $0.028/KWH OIL = $0.30/GAL ($/YR)
30	Purchased Power	1,384,122	1,641,098
	Total Energy	1,569,125	1,477,108
40	Purchased Power	1,279,520	1,514,889
	Total Energy	1,401,002	1,318,048
50	Purchased Power	1,242,103	1,445,064
	Total Energy	1,355,543	1,276,470
60	Purchased Power	1,144,106	1,409,506
	Total Energy	1,297,610	1,221,852

These results clearly show the high degree of sensitivity to the cost of energy. An increase in the electric rate of $0.007 per kilowatt-hour can change the annual cost of a purchased power system by approximately 18 percent and, similarly, a drop in the cost of diesel oil of $0.03 per gallon can mean a reduction in total energy annual costs of approximately six percent. With the changed energy estimates, Table 133 shows that a total energy system can have lower annual costs than purchased power. Due to this sensitivity to energy costs, the decision for or against either purchased power systems or total energy systems would have to be made after close analysis of the projected energy costs, and

other outside factors which might contribute to the final decision.

Recommendations. By comparing the annual costs of the three energy sources studied, purchased power systems were selected as the basic systems for projecting warehouse costs. Results of the comparison show that the average cost for total energy systems is approximately ten percent higher than for purchased power and that solar systems are not at all competitive since their costs are at least 50 percent higher than the purchased power costs. This analysis also shows that the selection of purchased power is insensitive to normal variances in the operating hours of the facility; however, this selection is highly sensitive to accurate projection of the anticipated costs and inflation rates for fuel and electricity. While the ten percent differential between the purchased power systems and the total energy systems indicates a selection of purchased power, the addition of building energy requirements, not available for this study, could reduce the differential or change the results if they lend themselves to the use of excess waste heat as an energy source. Items which might make a difference include domestic hot water requirements and process load requirements for material handling equipment requiring heat, such as steam cleaning equipment.

Other cost factors beyond the scope of this study might also be important factors in the selection of a source of energy for the warehouse. One factor with an apparent effect is the possibility of environmental hazard pay being required periodically in the general storage area if air conditioning is not installed. Current comfort standard recommendations from the American Conference of Government Industrial Hygienists

of Occupational Safety and Health (NIOSH) have not been adopted by the Occupational Safety and Health Administration (OSHA). However, the anticipated conditions in the warehouse facility with ventilation only could exceed the wet bulb globe index temperatures specified by NIOSH which represent the threshold levels for environmental conditions requiring hourly rest intervals. Currently, the DOD is receiving increasing pressure for additional payments of environmental hazard pay in existing warehouses with ventilation only (Milner, 1976). The GCE-76S study shows that for a total energy type system, where excess waste heat is available as an unused energy source, the increase in annual cost for the facility with the general storage area air-conditioned and humidity controlled versus the cost of the facility with ventilation only in the general storage area, is less than six percent ($90,000 per year). While a study of a totally air-conditioned building using purchased power was not conducted, information available through this study indicates that the differential costs would be greater than for a total energy system; but, they would still represent only a small percentage of the overall facility cost. Air conditioning the general storage area would tend to favor a total energy application where excess waste heat is available as an energy source; however, either type system might prove cost effective if material handling and personnel benefits exist.

A summary of recommendations relative to the preceding cost comparisons and discussions is given in the following list:

1. Use purchased power as the basic energy source for economic comparison.
2. Re-evaluate the study results with regard to the projected energy

costs and inflation rates for specific site locations under consideration.

3. Investigate cost savings available through air conditioning and humidity control of the general storage area.
4. Re-evaluate building energy requirements and energy source costs as material handling and processing equipment is defined.

Energy Monitoring and Control Systems

An Energy Monitoring and Control System (EMCS) allows the user of the facility to monitor and control systems within the facility from a central location. Such a system, when properly designed and utilized can significantly reduce operating cost; however, the amount of savings to be gained must be compared to the initial cost of the system (Haines, 1975:81). This section discusses the benefits that can be gained by such a system and presents a range of cost values for an EMCS that are dependent on the number of control points in the warehouse facility.

An EMCS can cut operating costs significantly. Controlling the energy requirements automatically from one central location can reduce labor costs. The air conditioning costs can be reduced by monitoring the facility environment and selectively controlling the number of chillers required to carry the cooling load. Electric demand can be programmed so as to shed loads, thus making it possible for the facility to stay outside commercial power penalty areas. In addition, load shedding can be programmed to shed electrical loads automatically in the event of a power failure, thus insuring that the backup equipment is on line in a minimum amount of time. Monitoring systems consisting of door alarms and closed circuit television can increase security and cut costs by reducing the number of security personnel required. Lighting systems can be controlled, insuring that unnecessary lights are off, again saving energy costs. Fire sensors can detect a fire, pinpoint the location, and notify the fire department automatically, thus providing a safer working environment.

Cost Determination. An EMCS can definitely increase the security and safety of a facility and reduce the operating costs. However, to determine

whether or not the system is economically feasible, the initial cost of the system must be determined.

The initial cost of the EMCS can be broken into three major areas: the control and monitoring point costs, the hardware costs, and the software costs. The number of control and monitoring points has the largest effect on the cost of EMCS.

Prior to determining the cost of hardware options, it is necessary to consider what type of hardware will be required. Listed below are the necessary hardware items and their function:

1. Clock Programmer - This allows certain functions within the building to be programmed to take place at a certain time.
2. Cathode Ray Tube Display - This displays the EMCS computer output on a cathode ray tube. At least two of these should be provided, one for the mechanical room and the other for the security control room.
3. Cathode Ray Tube Terminal - This allows the operator to enter data and to call computer programs. A minimum of two should be provided so that the mechanical room and the security control room would have access to the computer.
4. Intercommunications System - This system allows the operator to talk and listen to remote stations throughout the building plus monitor selected equipment.
5. Computer - This is a small computer with 16K core memory. This requirement may be deleted if the facility's master computer is used.
6. Printer - The printer prints out information concerning different

systems within the facility. It would be possible to keep these printouts as a permanent record. Both the mechanical room and the security control room should have a printer.

7. Color Graphic Projector and Slides - Certain building systems are diagrammed on color slides. This would allow the operator to pinpoint maintenance problems within that system.

The average cost for the hardware listed above is shown in Table 134. The software options that should be included are listed below:

1. Alarm Instructions - A program to initiate the printing of instructional messages should a monitoring point indicate a system is operating out of the selected tolerance.
2. Analog Limit Comparison - A program to provide a comparison of monitoring point values against preselected limits. If the monitoring point values are out of limits the program would initiate the alarm instruction program.
3. Automatic Restart of Pre-assigned Equipment Upon Resumption of Power - A program to restart equipment selectively when power is returned after an electrical power failure. If the facility were using commercial power the program would initiate proper load shedding, allowing the back-up power to be on line in a minimum of time. Under a total energy power system, the EMCS could be programmed to load shed, transfer loads, or bring standby power on line upon the loss of a primary generator or outage in the electrical distribution system.
4. Chiller Profile - A program that records the operating status of the chiller equipment under all cooling load conditions. A

set of historical data can be maintained and an optimum chiller schedule could then be determined. There are programs available to automatically distribute the cooling load among the chillers; however, since there is an operator on duty 24 hours a day this function could be handled manually with the same degree of efficiency.

5. Door Security System - A program that monitors the door security system. This system can include remote door lockings from a central point and an alarm system to notify the operator if a door is open or closed.
6. Elapsed Run-Time Records - A program that totals the run-time selected equipment within the building. This would assist in equalizing the equipment running time and provide a record so that scheduled maintenance could be performed in a timely manner.
7. Electric Demand Limiting - A program that monitors electric energy consumption. This would be used if commercial power is used in the facility. During periods of peak demand the operator can shed selected loads to keep the facility from operating in an electric penalty area.
8. Enthalpy Optimization - This program optimizes the outside air/return air mixing by comparing the outside air conditions with inside conditions. Approximately 25 air handling units in the facility would require this capability.
9. Life Safety and Emergency Routines - A program that would automatically initiate a series of commands in response to an emergency alarm. This system would be useful in the fire protection

system. A fire location would be pinpointed, the fire command station would be notified immediately, and the fire suppression system could be activated.

See Table 135 for the cost of the individual software items.

The number of control and monitoring points is the largest factor in determining the cost of an EMCS system. It is important that the number, the type, and the location of points be accurately determined in order to properly estimate a system cost. To determine the number of points required, the designer must examine the entire facility and consider whether the initial cost of the EMCS will be justified by the amount of money the system could save by optimizing energy consumption and manpower requirements. It is not possible to determine exactly how many points are required until a definite design has been accomplished and a determination of the material storage arrangement has been made. For example, in estimating the number of fire monitoring points, the number could vary greatly depending on the type of material stored, whether the material is in racks or not, the size of the fire enclosure, and so on. Because of the conceptual nature of this design study, GCE-76S did not accomplish a precise economic analysis on a particular EMCS system; however, the study presents the approximate cost of systems with 500, 1000, 1500, 2000, 3000, and 5000 control and monitoring points.

The cost of a close circuit television security system was not considered, although the type systems investigated could easily be modified to provide closed circuit television.

The cost listed for the control and monitoring points allow for 25 feet of hardware in conduit from each point to a remote terminal. These

remote terminals would be located throughout the facility and connected to the main terminal. An exact design and layout of the building is required to accurately locate these remote terminals. Actually the length of run from the remote terminal to the control point in some cases will be considerably longer than 25 feet while in other cases the length of run will be shorter. For this study, it was assumed that all runs from the control points to the remote terminals are 25 feet. The initial cost of the control and monitoring points are listed in Table 136.

The costs that have been presented are an average cost of the following manufacturers' systems:

1. Barber-Colman Company Econ VI
2. Honeywell Delta 2000 and Alpha 3000
3. Johnson Service Company JC - 80
4. Powers Regulator Company Model 570
5. Robertshaw Controls Company DMS - 2400

The cost information was obtained from a study done for the Naval Facilities Engineering Command. The annual cost for an EMCS system is presented in Figure 32. This annual cost includes the cost of maintaining the system. Because the costs are a rough estimate at best, the cost of the EMCS is not included in the total cost results for the structure. However, the results do give a general idea of what an EMCS would cost in the facility. Appendix E-13 shows the annual cost estimate for the EMCS.

Recommendations. GCE-76S recommends that an EMCS be considered for the facility. Certainly an EMCS can, if properly designed, save energy and manpower dollars. After a definite facility has been decided upon, an EMCS should be designed with the idea of optimizing the number of

control points. It is recommended that a thorough economic analysis be performed to insure the system is, in fact, the optimum for the particular facility.

TABLE 134

INITIAL EMCS HARDWARE COSTS *

ITEM	INITIAL COST
Clock Programmer	$ 250.00
Cathode Ray Tube Display	$10,000.00
Cathode Ray Tube Terminal	$20,000.00
Intercommunications System	$ 500.00
Mini-Computer - 16K Storage	$16,000.00
Printer	$20,000.00
Color Graphic Projector & Slides	$ 5,700.00
Total Hardware Costs	$72,450.00

* (Bosch, 1975:4.8)

TABLE 135

INITIAL EMCS SOFTWARE COSTS *

ITEM	INITIAL COST
Alarm Instructions With 100 Unique Messages	$13,000.00
Analog Limit Comparison	$ 1,000.00
Automatic Restart Of Preassigned Equipment Upon The Resumption Of Power	$ 3,500.00
Chiller Profile	$ 3,500.00
Door Security System	$ 2,500.00
Elapsed Run-Time Records For 50 Points	$ 3,700.00
Electric Demand Limiting With Automatic Load Shedding	$ 6,500.00
Enthalpy Optimization At 25 Air Handling Units	$10,800.00
Life-Safety And Emergency Routines	$ 6,500.00
Total Software Costs	$51,000.00

*(Bosch, 1975:4.8)

TABLE 136

INITIAL COST OF CONTROL AND MONITORING POINTS *

NUMBER OF POINTS	COST PER POINT	TOTAL COST
500	380	$ 190,000
1,000	350	$ 350,000
1,500	340	$ 510,000
2,000	340	$ 680,000
3,000	340	$1,020,000
5,000	340	$1,700,000

* (Bosch, 1975:4.8)

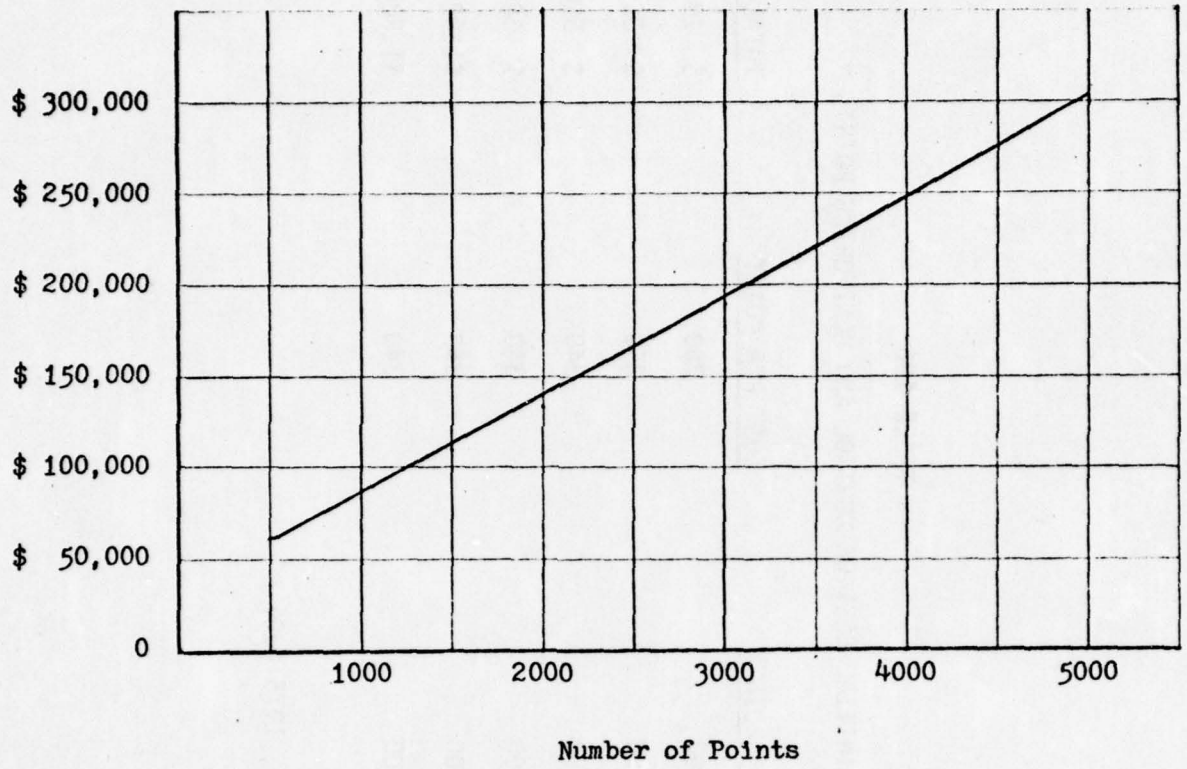


FIGURE 32 ANNUAL COST OF EMCS VS THE NUMBER OF CONTROL AND MONITOR POINTS

Freezer/Cooler

The freezer and cooler areas are special areas of the warehouse design on which the EATG study group asked for separate cost information. Because of the unique design considerations and the request for separate cost information, the freezer and cooler were treated independently. This section of the report mainly discusses the design of the refrigeration system. At the end of the section, price information for the structure and lighting will be incorporated to give a total cost for the area.

The first subject of this section is the design parameters given by the EATG study group in the statement of work and subsequent meetings, then the limitations and assumptions necessary to start the design are presented. Next, the peak cooling loads on the refrigeration system and how they were developed is covered. Determination of the building energy requirements and refrigeration equipment selection are the next two subjects. Evaluation of the types of insulation and the effect of insulation thickness on operating costs is then discussed and the last subject is the total freezer/cooler costs and recommendations.

Given Design Parameters. As part of the preliminary design and costing of the 50 acre warehouse, the EATG study group asked that the cost of a million cubic feet of freezer and chilled space, or cooler, be provided. Originally this area was supposed to be an integral part of the warehouse and varied in height as the warehouse roof height was varied. On 20 April, 1976, three members of the GCE-76S class went to Tobyhanna Army Depot, Pa. for a conference with Mr. Tom Vrba of the EATG study group and his staff. Part of the results of this conference were finalization of the design parameters provided by the EATG and the information they

needed. The results of this conference pertaining to the freezer and cooler area are listed below:

1. The freezer and cooler area is a total of one million cubic feet. Two thirds of this area is cooler and one third is freezer.
2. The freezer and cooler area was moved out of the warehouse and now is treated as a separate building.
3. The cooler is designed to maintain $32^{o}F$.
4. Operation costs are also provided for the cooler maintained at $40^{o}F$ and $50^{o}F$ using the same refrigeration equipment.
5. The freezer is designed to $-10^{o}F$. This temperature was chosen because it is the recommended temperature for freezers (ASHRAE, 1971:447).
6. There are four people working in the freezer and 12 people working in the cooler. All the people will be working from 0800 to 1600 hours on weekdays and no people will be working on weekends.
7. There are no internal heat loads from electric motors, because only battery operated fork lifts will be used.
8. This freezer and cooler will be used for storing and distributing batteries, photographic supplies, chemicals, and medical supplies. There will be no food stored in this area.
9. The roof height was set at 30 feet.
10. The building configuration was agreed to and is shown in Figure 33

These are the given design parameters on which the freezer and cooler design is based. The next step was to determine the initial limitations and assumptions necessary to design the freezer and cooler.

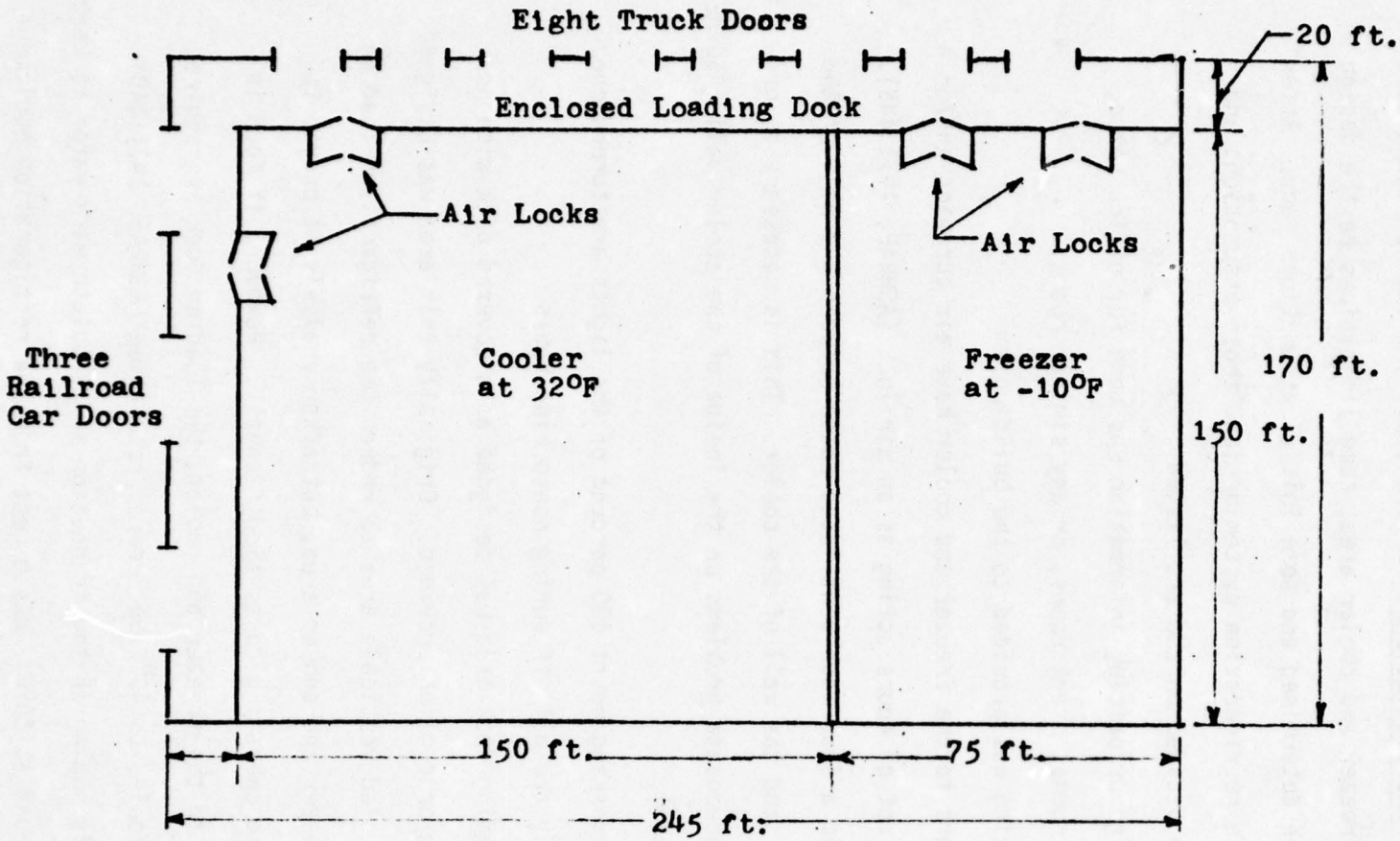


FIGURE 33 FREEZER/COOLER LAYOUT

Assumptions and Limitations. Before designing the refrigeration system for the freezer and cooler area, some limitations to the design problem had to be determined and some initial assumptions made. After research into the refrigeration system design, these assumptions and limitations were decided on and are listed.

1. No design or pricing information was done for office space, locker rooms, break rooms, or any similar rooms.
2. No heating was provided to the building.
3. The doors to the freezer and cooler have air curtains and/or a double set of doors acting as an air lock (ASHRAE, 1971:445).
4. There is a four inch ventilated space between the wall of the freezer and the wall of the cooler. This is necessary to prevent condensate problems on the inside of the cooler wall (ASHRAE, 1972b:413).
5. During working hours 100 percent of the lights are turned one, and they are all off during nonworking hours.
6. The loading dock area was designed as a covered dock with no heating or cooling provided. Originally this area was designed as a cooled vestibule area to reduce the refrigeration load on the freezer and cooler area, but after analysis it proved to increase operating costs significantly. However, if food is stored in the freezer and cooler, the loading dock is required to be cooled to $45^{o}F$ by federal regulation (ASHRAE, 1971:448).
7. There is piping in the foundation to circulate warm water to keep the ground at $40^{o}F$. Waste heat from the refrigeration equipment condensor is used to warm the water. This circulation of warm

water is necessary to keep the ground from freezing and causing frost heave damage (ASHRAE, 1972b:413).

With the given design parameters, limitations, and initial assumptions, the design problem could be further defined and the peak cooling loads on the refrigeration equipment could be calculated.

Peak Loads. The next step in the design was to identify the different types of cooling loads on the refrigeration system and calculate the peak values for these cooling loads. This process was accomplished using the ASHRAE Total Equivalent Temperature Differential Method explained in the "HVAC Loads" section of this report, with slight modification for the low temperatures in the freezer and cooler. All cooling loads were determined using the peak design day for Norfolk, Va. This peak design day is at 95°F dry bulb temperature and 78°F wet bulb temperature.(Carrier, 1972:15). An explanation of how these peak loads were calculated follows, and the actual values of the peak loads and their totals, or peak design loads of the freezer and cooler, are presented in Table 137.

The first four loads are internal cooling loads and are from heat given off by the air handler motors, the cooling of the product, the people, and the lights. The air handler cooling load was calculated by using the temperature difference between supply air and room air to determine the required cubic feet per minute of air and using fan curves to obtain the required horsepower of the fan (see Appendix E-14 for sample calculations). This fan horsepower was converted to a heat load expressed as BTU per hour by the same method used in the "HVAC Loads" section of this report. The number of people working in the freezer and cooler was given by the EATG, and this number was multiplied by the heat given off by one person to

TABLE 137

PEAK COOLING LOADS

TYPE LOAD	COOLER (BTU/HR)	FREEZER (BTU/HR)
Air Handlers	190,875	101,800
Cooling Of Product	1,012,500	506,800
People	11,400	5,600
Lights	28,140	14,070
Air Infiltration	143,520	100,860
Transmission	117,680	111,330
Solar	32,976	15,500
Total	1,537,091	855,410
Air Conditioning Required	128 Tons	71 Tons

obtain the peak load (ASHRAE, 1972a:448). The lighting load was determined by obtaining the power input of the lights from the "Lighting Design" section of this report and converted it to a heat gain by the method used in the "HVAC Loads" section.

The last internal load is the major load on the system. This is the amount of heat given off by bringing into the chilled space new products that are slightly warmer than the maintained temperature. This is a load on the system even if the product is received prefrozen or prechilled. By the time a shipment is unloaded from a truck or railroad car and processed it has warmed up to some degree (Kronholz, 1976). This load was based on introducing new products at a rate equal to five percent of the total storage volume per hour. The rate of volume flow was specified by EATG (Vrba, 1976). The weight and specific heat were determined by estimating the average value for stored items (ASHRAE, 1972a:571). This was calculated by Equation (30).

$$Q = Wc(t_1 - t_2) \qquad (30)$$

where:

Q = Heat removed in BTUH

W = Weight of product

c = Specific heat of product

t_1 = Initial temperature

t_2 = Final temperature, or temperature of chilled space (ASHRAE, 1972a: 446)

See Appendix E-14 for the actual calculation of this cooling load. This is the final internal load, and air infiltration is the next cooling load calculated.

Air infiltration is a load caused by the loss of cold air and the influx of warm air through the doors. The amount of air flowing through the doors is about one air change per day or slightly less, for normal operations of a freezer and cooler area this large (ASHRAE, 1972a:446) (Kronholz, 1976). Seven tenths of an air change per day was used, which converted to 1000 cubic feet per minute for the cooler and 500 cubic feet per minute for the freezer. This was converted to heat gain by using factors out of ASHRAE for refrigerated spaces (ASHRAE, 1972a:447).

The transmission load is calculated by multiplying together the coefficient of heat transfer (U), the surface area, and the temperature difference across the roof, floor, and walls. The U values used were .04 BTU per hour-square foot for the freezer and .05 BTU per hour-square foot for the cooler (ASHRAE, 1972a:446)(ASHRAE, 1972b:413). Originally, a U = .03 BTU per hour-square foot was used for both the freezer and cooler, but after comparing insulation cost versus operating costs the new values were more economical. This insulation check will be discussed in detail later.

The last cooling load is the solar load, which is the heat added to the area by solar radiation. The equivalent temperature differentials were obtained from ASHRAE based on medium weight walls and roof and a temperature differential of 105°F for the freezer and 63°F for the cooler (ASHRAE, 1972a:415). The solar load was then determined by the ECUBE energy requirements computer program, which compared the heat gain through the walls and roof based on the equivalent temperature differentials and the transmission heat gain to determine the solar load.

The design peak load is the load on the refrigeration system if all

the different loads are at their peak value at the same time. It is the sum of all the peak values of the cooling loads in Table and is shown as the total in Table . These totals convert to 128 tons of refrigeration required for the cooler and 71 tons of refrigeration for the freezer. These design peak loads were used for sizing the refrigeration equipment, but to calculate the operating costs the annual energy requirements had to be determined.

Energy Requirements. The ECUBE energy requirements computer program, previously discussed in the "HVAC Energy Requirements" section, was used for calculating the freezer and cooler annual energy requirements. The peak cooling loads, building properties, peak electric power consumption, and profiles of how these loads vary with time or temperature were input to the computer program. The computer program simulated the building operation for one year and determined the annual energy requirements.

The four internal cooling peak loads (air handler motors, cooling of product, people, and lights) and their hourly variances were input to ECUBE. People, lights, and cooling of product were considered to be system loads during the eight hour workday and zero load at all other times. These load variance profiles were time integrated for storage effect exactly the same way it was done in the "HVAC Energy Requirements" section. The air handler motor load was considered to be 80 percent of peak at all times, because the refrigeration equipment runs 80 percent of the time (this is explained further in the next section). The peak kilowatt loads for the lights and air handler motors were input to ECUBE along with the same time variance profiles as the cooling loads.

The air infiltration, transmission, and solar load were the last three

inputs. The air infiltration and transmission loads vary with outside air conditions, so the cooling load of each was input for three different outside temperatures. ECUBE calculates transmission load for each hour of the year, while the air infiltration load is only figured during working hours when the doors are open. As previously mentioned the solar load is calculated by the computer program.

From these inputs, ECUBE calculated the total annual energy requirements. The output contains considerable information, but the hourly and yearly totals of BTU per hour of refrigeration required and the electrical consumption are most important. Those values were used to calculate the annual yearly energy input for the refrigeration systems and the building, during the equipment selection phase.

Equipment Selection. With the freezer and cooler energy requirements established, the refrigeration system selection was accomplished. First, it was decided which type of refrigeration system to use and the design parameters on which its performance would be based. The next step was to design four variations of the system for the freezer and cooler by changing the number of compressors or the way the compressors split the load. By use of the ECUBE equipment selection program, the annual input of electricity was determined for each system. These systems were then compared based on total life cycle costs using the annual cost method. Using this life cycle cost and reliability factors, the best system was established.

The refrigeration system most widely used for freezer and cooler applications is a direct expansion system. This means the primary refrigerant is used in the air handler coil in the refrigerated space instead of a secondary coolant, such as water or a brine solution (ASHRAE, 1971:457).

Water cooled condensers maintained at 90°F were used and two or three reciprocating compressors were used, depending on the system variation. The evaporator coil refrigerant temperature was set at -25°F for the freezer and at 15°F for the cooler (Jenkins, 1976)(Kronholz, 1976). This was done to prevent large temperature drops in the circulating air across the coil and lowering the humidity level to a point where it could dry out stored items (ASHRAE, 1971:457). Because of this temperature difference the freezer and cooler each has its own independent refrigerant system. The refrigeration system was designed to run eighty percent of the time, and the other twenty percent of the time it is automatically defrosting the evaporative coils. This is accomplished by the "hot gas method", which consists of reversing refrigerant flow and pumping hot refrigerant through the evaporative coil (ASHRAE, 1972a:448)(Kronholz, 1976). So the basic system is a straight refrigeration cycle using only primary refrigerant and designed to the parameters explained above.

The refrigeration cycle efficiency is affected by the number of compressors and the schedule for turning the compressors on and off as the load increases and decreases. Four systems were analyzed for both the freezer and the cooler and are shown in Table 138. The compressors listed, their tonnage ratings, and input power were taken from a York refrigeration catalogue (York, 1972:15-18). Their operating schedules were input to the ECUBE equipment selection program (AGA, 1975:41). Two equipment operating schedules were evaluated. For schedule one, the first compressor carries the full cooling load until rated capacity is reached. The second compressor is then started and picks up that portion of the load in excess of the rated capacity of the first compressor, etc. Schedule two is the

TABLE 138

REFRIGERATION SYSTEMS

TYPE SYSTEM	OPERATING SCHEDULE	REFRIGERATION CAPACITY (TONS)	INPUT ENERGY (KW)
		FREEZER	
3-8 Cylinder Compressors (R-22) *	1	75.9	153.4
3-8 Cyclinder Compressors (R-22)	2	75.9	153.4
2-12 Cylinder Compressors (R-22)	1	76.0	153.4
2-12 Cylinder Compressors (R-22)	2	76.0	153.4
		COOLER	
3-6 Cylinder Compressors (R-22) *	1	168.9	188.4
3-8 Cylinder Compressors (R-12)	1	137.4	154.3
2-8 Cylinder Compressors (R-22)	1	150.2	166.9
3-6 Cylinder Compressors (R-22)	2	168.9	188.4

* Selected system

same except the load is shared equally by all compressors.

The information from Table 138 and the partial performance data of the compressors from the technical data in the catalogue were inputed to the ECUBE equipment selection program. The program used this input and the output of the energy requirements program to calculate the total electric consumption for a year for each area. The output of this program is in Tables 139 and 140. These tables list the systems, the yearly kilowatt consumption of the area using that refrigeration system, the peak kilowatt demand for the area, and the hours per year each compressor operates. With this data, it was now possible to select a refrigeration system.

The different refrigeration systems were evaluated by life cycle cost for 25 years using the annual cost method. The inflated electric rate of $0.0441 per kilowatt-hour (see Appendix E-1) and a ten percent annual interest were used for the comparison. The installed price of the systems and the annual maintenance cost were obtained from the manufacturer (Kronholz, 1976). The maintenance cost is based on a contract with the manufacturer to provide all maintenance. Using the above mentioned figures, the life cycle costs were calculated for each refrigeration system and are presented in Appendix E-14.

The three-compressor systems were chosen as the best systems, and they are presented, along with their life cycle costs, in Table 141. These systems are slightly more expensive than the two-compressor systems ($186 per year for the freezer and $71 per year for the cooler, Appendix E-14). However, if a compressor breaks down they can handle 71 percent of the peak load for the freezer and 88 percent of the peak load for the cooler; whereas, the two compressor systems can only handle 54 percent of peak load for the

TABLE 139

COOLER REFRIGERATION SYSTEM PERFORMANCE AND CONSUMPTION

	3-6 CYL. COMPRESSORS SCHED. 1	3-8 CYL. COMPRESSORS SCHED. 1	2-8 CYL. COMPRESSORS SCHED. 1	3-6 CYL. COMPRESSORS SCHED. 2
Electrical Consumption (KWH)	626,476	622,703	636,217	627,051
Peak Electrical Demand (KW)	209	208	208	211
Compressor Operating Hours				
#1	8,760	8,760	8,760	8,760
#2	2,510	2,510	2,124	2,510
#3	736	2,008	---	736

TABLE 140

FREEZER REFRIGERATION SYSTEM PERFORMANCE AND CONSUMPTION

	3-8 CYL. COMPRESSORS SCHED. 1	3-8 CYL. COMPRESSORS SCHED. 2	2-12 CYL. COMPRESSORS SCHED. 1	2-12 CYL. COMPRESSORS SCHED. 2
Electrical Consumption (KWH)	678,865	683,091	690,800	691,324
Peak Electrical Demand (KW)	191	192	191	191
Compressor Operating Hours				
#1	8,760	8,760	8,760	8,760
#2	2,510	2,510	2,510	2,510
#3	2,510	2,510	---	---

TABLE 141

REFRIGERATION SYSTEMS COST

	FREEZER	COOLER
Selected System	3-8 Cylinder Compressors	3-6 Cylinder Compressors
Operating Schedule	1	1
Installed Purchase Price (Annual Cost)	$17,763	$20,205
Annual Energy Cost (Inflated)	$29,938	$27,628
Annual Maintenance Cost	$14,938	$17,628
Total Annual Cost	$62,595	$65,761

freezer and 59 percent for the chiller. The greater refrigeration capacity of the three compressor system was considered more important than the slight increase in cost. With this capacity, if a compressor fails, most times of the year the refrigeration system can meet the load. If a compressor fails during peak load conditions, slowing the rate of introducing new products, which is the major cooling load, will allow the system to meet the total load. If a backup compressor is desired, the three compressor system becomes less expensive than the two compressor system, because it uses smaller and cheaper compressors. With the best refrigeration system chosen and costed, the next step was to evaluate the insulation and its effect on the refrigeration system.

Insulation Check. Because of the low temperatures in the freezer and cooler, the type of insulation used and the U value (coefficient of heat transfer) obtained has great effect on the overall construction costs and operating costs. For this reason, studies were made on three types of insulation and on the trade off between insulation costs and operating costs.

The types of insulation used can affect the price of construction. The comparison is difficult to make because the thermal resistances of insulation varies significantly from one reference to another. The values of thermal resistance used to calculate the insulation required is an average of two sources (ASHRAE, 1972a:364)(Dow, 1971). The most commonly used insulations are styrofoam, urethane, and mineral wool. See Table 142 for the comparison of the insulation costs based on the freezer design conditions. The chart is approximate, but follows the industry practice and recommendations, which are to use the cheaper styrofoam except where

TABLE 142

INSULATION COMPARISON *

TYPE INSULATION	INCHES REQUIRED	COST/INCH **	TOTAL COST
Styrofoam	5.25	$0.235	$1.54
Expanded Urethane	3.50	$0.400	$1.75
Mineral Wool	6.00	$0.230	$1.73

** (Craftsman, 1975)

* Based on U = .04 BTU/hr-sq ft at -10°F and one square foot of surface area.

space is critical, then use urethane (Dow, 1971). So the pricing of insulation was accomplished using styrofoam, since no space constraints were given. This makes the walls thicker.

The next study made was on the trade off between insulation costs and operation costs. The operation costs were determined for three different U values. This was done by calculating the annual electric consumption using ECUBE and multiplying by the inflated energy rate. Then the insulation cost was computed based on the depth of insulation needed to maintain that U value. Appendix E-14 contains the calculations made for this comparison, and the results are shown in Figures 34 and 35. These figures represent approximate cost data based on preliminary design and include only insulation and operating costs. The minimum annual costs are approximately at U = .035 for the freezer and at U = .07 for the cooler. These values are very close to the recommended thickness of insulation for the operating temperatures (Dow, 1971)(ASHRAE, 1972a: 446). The freezer was designed to a U = .04 and the cooler to a U = .05. The freezer value is designed to meet the requirements, and the cooler is slightly over insulated. The cooler U value was based on an initial estimate of a break even point and could have been changed, time permitting, but the extra insulation only adds $600 to the annual cost which is very small compared to the overall annual cost. The results of this test show that the trade off between insulation costs and operating costs is very significant in freezer and cooler design.

Freezer/Cooler Cost and Recommendations. With the best refrigeration system selected and its cost determined, the total cost of the freezer/cooler area was determined. This cost was developed as an annual cost

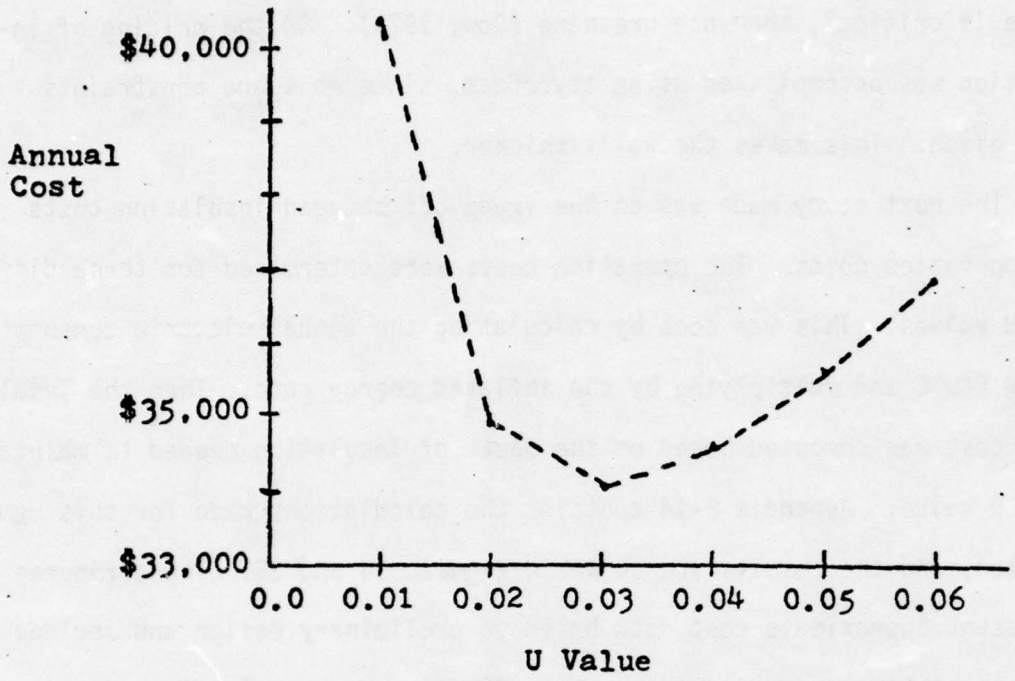


FIGURE 34 FREEZER INSULATION AND OPERATING COST VARIATION WITH U VALUE

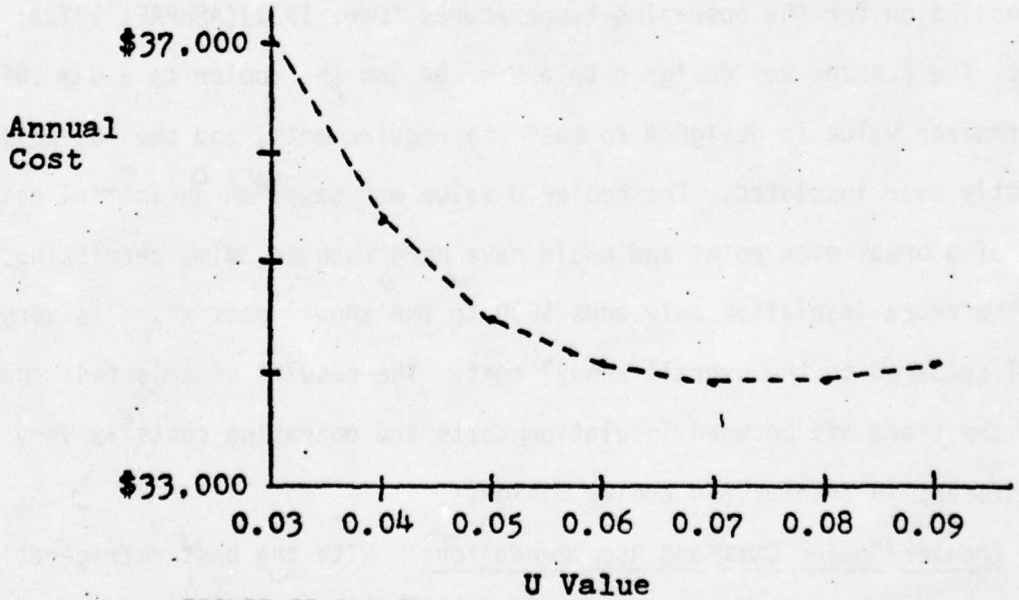


FIGURE 35 COOLER INSULATION AND OPERATING COST VARIATION WITH U VALUE

including both construction cost and annual operating and maintenance costs. The total cost was based on a 25 year life, ten percent interest rate, and uninflated electric rate of $0.021 per kilowatt-hour. This cost is based only on the freezer, cooler, and loading dock areas. Office space, break rooms, locker rooms, and other similar areas were not considered. The cost was developed by first determining the total cost for each area and summing up these costs to obtain the total costs. The cost information for each area and the calculations made to determine it are in Appendix E-14.

The total cost of the building and the different costs contributing to the total cost are presented in Table 143. The building shell cost consists of the cost of structural steel, foundation, roof, and walls. These were calculated from the cost data provided by the "Civil Engineering" section and based on a 30 foot high building and 1000 pounds per square foot floor loading. The special construction cost is the total cost of additional construction necessary to convert the building shell into a freezer/cooler area. The costs for the special construction are all based on two pricing guides (Craftsman, 1975)(Means, 1975). The energy system capital costs is the sum of the refrigeration systems cost developed in this section and the lighting systems cost from the "Lighting Design" section. Operating annual costs were determined by multiplying the total electric consumption, as determined by ECUBE, by the uninflated electric rate. The maintenance cost is the sum of the refrigeration systems maintenance cost and the lighting systems maintenance costs. The total annual cost is the sum of the total purchase cost converted to an annual cost, the operating cost, and maintenance cost.

TABLE 143

TOTAL FREEZER AND COOLER COSTS

TYPE COSTS	CAPITAL COSTS	ANNUAL COST VALUE
Building Shell	$ 523,420	$ 58,109
Special Construction	$ 502,977	$ 55,839
Energy Systems	$ 422,446	$ 46,898
Total Purchase Cost	$1,448,843	$160,846
Operations Cost	---	$ 28,574
Maintenance Cost	---	$ 33,436
Total Annual Cost	---	$222,856

The total annual cost is an approximate value, based on a preliminary design. Many prices were taken from pricing guides. Also the total annual cost does not include office space, break rooms, or any other rooms necessary for worker comfort. These rooms would most likely be in the building and would add to the cost.

The last cost data given is the comparison of annual cost for different operating temperatures of the cooler. Table 144 gives the total annual cost for the cooler and the total freezer/cooler area for the three operating temperatures requested. Increasing the operating temperature of the cooler does decrease the annual cost, but the change is insignificant to overall annual cost.

There are three observations to be made from this study, to go along with the cost data. The first one is to remember that the annual cost derived in this section is approximate. It is accurate enough for the comparison studies the EATG plans to make, but for contract purposes a much more detailed design and pricing study would have to be made. The detailed design should make a study of the trade off between insulation costs and operating cost to determine the optimum amount of insulation. This can be done quickly and easily with an energy usage computer program such as ECUBE. The rate of introducing new products to the chilled space and the type of products is the major load on the refrigeration system. If it is not carefully analyzed the refrigeration system can be undersized or oversized.

TABLE 144

VARIATION OF COOLER OPERATING TEMPERATURE

OPERATING TEMPERATURE (°F)	TOTAL ANNUAL COOLER COST ($/YEAR)	TOTAL ANNUAL BUILDING COST ($/YEAR)
32	115,554	220,256
40	114,662	219,364
50	114,277	218,979

Internal Energy Systems Cost Summary

The energy systems cost is presented as an annual cost per thousand cubic feet. The annual cost was obtained by summing the capital costs of the equipment amortized over 25 years at a ten percent interest rate and the yearly maintenance and energy consumption costs. This cost for the entire facility was further broken down into the annual costs per thousand cubic feet of operating area, mechanized area, and general storage area.

ECUBE was used to determine the yearly electrical energy consumption in KWH and the yearly electrical energy cost in dollars for the operating area, the mechanized area, the general storage area, and the mechanical equipment room. The uninflated cost of electricity was taken to be $.021/KWH. This rate was determined to be the rate paid by Langley AFB during 1975. A rate of $.0441/KWH was also used to include the effects of inflation. This inflated rate was obtained by averaging over a 25 year period the current rate of $.021/KWH inflated by ten percent over the first ten years and constant at the tenth year rate over the remaining 15 years.

Table 145 shows the yearly electrical energy consumption in KWH for this facility. The table is subdivided to separate the energy consumed by the functional areas of the facility and the energy consumed by the mechanical equipment room to provide heating, ventilation or air conditioning as required. The percentages of the electrical energy consumption subtotals for the operating area, the mechanized area, and the general storage area are also shown in Table 145. These percentages were used to proportion the cost of some of the equipment, such as the standby generators, that are required to support this facility.

Table 146 shows the yearly cooling consumption in MBTUH required for this facility. The percentages of the cooling consumption for each of the areas are also shown in parenthesis. These percentages were used in allocating in proportionate shares the yearly electrical energy consumption of the mechanical equipment room in Table 146 to the operating area and the mechanized area.

The yearly electrical energy costs at the uninflated and the inflated rates are shown in Tables 147 and 148. Table 147 shows the cost of energy consumed by the three areas. Table 148 shows the cost of energy consumed by the mechanical equipment room allocated to the three areas by percentages determined in Table 146.

The capital cost and the yearly maintenance cost for the uninterruptable power system, the standby generators, and the primary substation switch gear were distributed to the three areas by using the percentages developed in Table 145. These items support all three areas in proportion to the electrical energy consumption percentages developed in Table 145.

The capital and the yearly maintenance cost for the chillers, the water pumps, the cooling towers, the air handling units, and the ducts and piping were distributed by using the percentages developed in Table 146. These items support only the operating area and the mechanized area in proportion to the cooling consumption percentages developed.

The capital cost and the yearly maintenance cost for the lights and associated circuits, the fans, and the emergency lights and associated circuits in the three areas were calculated by determining the actual number of each item in each area. The capital cost for the electrical distribution system to the mechanical equipment room was distributed to the three areas

by using the percentages developed in Table 146. The remaining capital cost for the distribution system in the three areas were determined by calculating the actual cost for each area.

The capital cost of the boiler in the mechanical equipment room was distributed to the three areas in proportion to the amount of external wall surface area. The boiler is used for perimeter heating during the winter only.

Tables 149 and 150 show the energy system equipment capital cost total and cost per thousand cubic feet, respectively. Tables 151 and 152 show the sum of the yearly maintenance and energy consumption cost total and per thousand cubic feet at an uninflated electric rate of $0.021 per kilowatt-hour. Tables 153 and 154 show the same values at the inflated electric rate of $0.0441 per kilowatt-hour. Tables 155 and 160 show the annual cost and annual cost per thousand cubic feet, which includes the capital cost and the yearly maintenance and energy consumption costs, at the uninflated rate. Tables 157 and 158 show the annual cost values for the inflated electric rate.

Cost values for the co-located freezer/cooler are shown in the next four tables. Tables 159 and 160 give the capital, yearly maintenance and electric, and annual cost values in total dollars and dollars per 1000 cubic feet, respectively, using base rate, uninflated, electricity costs. Tables 161 and 162 give the same costs using the inflated rate for electricity.

TABLE 145

YEARLY ELECTRICAL ENERGY CONSUMPTION (KWH)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA	FUNCTIONAL AREA SUBTOTAL	MECHANICAL EQUIP ROOM	TOTAL
30	6,151,126 (26.6%)*	12,203,852 (52.8%)*	4,758,887 (20.6%)*	23,113,866	1,835,274	24,949,140
40	6,150,395 (29.0%)*	9,323,741 (44.1%)*	5,700,405 (26.9%)*	21,174,541	1,562,259	22,736,800
50	6,149,695 (30.0%)*	7,869,214 (38.3%)*	6,507,661 (31.7%)*	20,526,571	1,333,783	21,860,354
60	6,149,106 (31.2%)*	6,733,022 (34.2%)*	6,827,081 (34.6%)*	19,709,209	1,203,414	20,912,623

TABLE 146

YEARLY COOLING CONSUMPTION (MBTUH)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA	FUNCTIONAL AREA SUBTOTAL	MECHANICAL EQUIP ROOM	TOTAL
30	7,757,184 (30.2%)*	17,925,026 (69.8%)*	0 (0%)*	25,682,210	0	25,682,210
40	7,738,290 (36.6%)*	13,427,610 (63.4%)*	0 (0%)*	21,165,900	0	21,165,900
50	7,720,007 (40.3%)*	11,423,453 (59.7%)*	0 (0%)*	19,143,461	0	19,143,461
60	7,701,604 (44.1%)*	9,754,203 (55.9%)*	0 (0%)*	17,455,807	0	17,455,807

* Percentage of functional area subtotal

TABLE 147

YEARLY ELECTRICAL ENERGY COST ($/YR) *

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA
30	129,174	256,281	99,937
	271,265	538,190	209,867
40	129,158	195,799	119,709
	271,232	411,177	251,388
50	129,144	165,253	136,661
	271,202	347,032	286,988
60	129,131	141,393	143,369
	271,176	296,926	301,074

TABLE 148

YEARLY ELECTRICAL ENERGY COST FOR MECHANICAL EQUIPMENT ROOM

DISTRIBUTED BY FUNCTIONAL AREA ($/YR) *

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA
30	11,687	27,012	0
	24,543	56,725	0
40	12,905	22,354	0
	27,098	46,943	0
50	11,266	16,690	0
	23,659	35,048	0
60	11,149	14,132	0
	23,412	29,677	0

* First entry is at $.021/KWH and second entry is at $.0441/KWH

TABLE 149

ENERGY SYSTEMS EQUIPMENT CAPITAL COST SUMMARY ($)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY TOTAL
30	1,005,998	1,783,089	913,453	3,702,540
40	1,063,946	1,506,490	1,025,577	3,596,013
50	1,119,002	1,427,118	1,153,904	3,700,024
60	1,140,421	1,270,130	1,132,996	3,543,547

TABLE 150

ENERGY SYSTEMS EQUIPMENT CAPITAL COST SUMMARY

($/1000 CU FT)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY AVERAGE
30	76.56	128.65	23.30	55.92
40	80.97	81.52	19.62	42.86
50	85.16	61.78	17.66	36.42
60	86.79	45.82	14.45	29.71

TABLE 151

YEARLY MAINTENANCE AND ENERGY COST SUMMARY

NO INFLATION ($)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY TOTAL
30	157,680	304,227	115,260	577,167
40	159,651	236,359	135,384	531,394
50	158,863	199,815	153,549	512,227
60	160,177	171,864	159,168	491,209

TABLE 152

YEARLY MAINTENANCE AND ENERGY COST SUMMARY

NO INFLATION ($/1000 CU FT)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY AVERAGE
30	12.00	21.95	2.94	8.72
40	12.15	12.79	2.59	6.34
50	12.09	8.65	2.35	5.04
60	12.19	6.20	2.03	4.12

TABLE 153

YEARLY MAINTENANCE AND ENERGY COST SUMMARY

WITH INFLATION ($)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY TOTAL
30	312,601	615,938	225,423	1,153,962
40	315,886	476,414	267,110	1,059,410
50	313,389	399,861	303,831	1,017,081
60	314,440	342,896	316,768	974,105

TABLE 154

YEARLY MAINTENANCE AND ENERGY COST SUMMARY

WITH INFLATION ($/1000 CU FT)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY AVERAGE
30	23.79	44.44	5.75	17.43
40	24.04	25.78	5.11	12.63
50	23.85	17.31	4.65	10.01
60	23.93	12.37	4.04	8.17

TABLE 155

ENERGY SYSTEMS ANNUAL COST SUMMARY

NO INFLATION ($)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY TOTAL
30	268,450	500,623	216,014	985,087
40	276,860	402,310	248,292	927,461
50	282,116	357,126	280,962	920,204
60	285,795	311,850	283,837	881,482

TABLE 156

ENERGY SYSTEMS ANNUAL COST SUMMARY

NO INFLATION ($/1000 CU FT)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY AVERAGE
30	20.43	36.12	5.51	14.88
40	21.07	21.77	4.75	11.06
50	21.47	15.46	4.30	9.05
60	21.75	11.25	3.62	7.39

TABLE 157

ENERGY SYSTEMS ANNUAL COST SUMMARY

WITH INFLATION ($)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY TOTAL
30	423,371	812,335	326,177	1,561,883
40	433,094	642,365	380,017	1,455,477
50	436,642	557,172	431,244	1,425,058
60	440,059	482,882	441,437	1,364,378

TABLE 158

ENERGY SYSTEMS ANNUAL COST SUMMARY

WITH INFLATION ($/1000 CU FT)

BLDG HEIGHT (FT)	OPERATING AREA	MECHANIZED AREA	GEN STOR AREA	FACILITY AVERAGE
30	32.22	58.61	8.32	23.59
40	32.96	34.76	7.27	17.35
50	33.23	24.12	6.60	14.02
60	33.49	17.42	5.63	11.44

TABLE 159

FREEZER/COOLER COSTS

NO INFLATION ($)*

	CAPITAL	YEARLY ENERGY & MAINTENANCE	ANNUAL
Freezer	522,360	29,399	86,947
Cooler	760,146	31,193	114,938
Loading Dock	166,337	1,455	19,780
Total	1,448,843	61,987	221,665

TABLE 160

FREEZER/COOLER COSTS

NO INFLATION ($/1000 CU FT)*

	CAPITAL	YEARLY ENERGY & MAINTENANCE	ANNUAL
Freezer	1,548	87	258
Cooler	1,126	46	170
Loading Dock	702	6	83
Average	1,160	50	177

*Costs include building construction and HVAC

TABLE 161

FREEZER/COOLER COSTS

WITH INFLATION ($)*

	CAPITAL	YEARLY ENERGY & MAINTENANCE	ANNUAL
Freezer	522,360	45,081	102,629
Cooler	760,146	45,665	129,410
Loading Dock	166,337	2,733	21,058
Total	1,448,843	93,479	253,098

TABLE 162

FREEZER/COOLER COSTS

WITH INFLATION ($/1000 CU FT)*

	CAPITAL	YEARLY ENERGY & MAINTENANCE	ANNUAL
Freezer	1,548	134	304
Cooler	1,126	68	192
Loading Dock	702	12	89
Average	1,160	75	203

* Costs include building construction and HVAC

Cost Data Sensitivity Analysis. The cost data provided was developed based on the parameters and assumptions presented in the preceeding sections of the report. Analysis of the results shows that the most important variable in determining the "dollars per 1000 cubic foot" cost values is the assumed installed level of energy consumption. The capacities, expressed as installed kilowatt load per cubic foot, used to compute the given cost estimates, are listed in Table 163. These capacities, power levels, were calculated by adding the peak kilowatt loads for the building lights, material handling equipment, and HVAC equipment.

TABLE 163

INSTALLED POWER LEVEL (KW/CU FT)

BLDG HEIGHT (FT)	OPER AREA	MECH AREA	GEN STOR AREA
30	.138	.283	.029
40	.138	.167	.026
50	.138	.113	.024
60	.138	.081	.021

Plotting the building cost values versus the associated power level values shows that there is a proportional relationship between cost and the kilowatt requirements. This is a very reasonable finding; since, most costs associated with internal energy systems can be expressed directly in terms of kilowatt capacity. Since the installed power level is the primary variable in building costs, the following recommendations are made

for scaling building size.

For the operating area, due to the small diversity in the cost data which reflect interdependence on other areas of the building, it is recommended that the highest cost values be used as a cost estimate. Use of these values is based on the restriction that as the zone volume is changed, the installed electrical equipment must be changed to hold the power level at 0.138 kilowatts per cubic foot. This was the only power level covered by this study for the operating area and any changes would be outside the limitations of the cost data provided. The recommended cost values for internal energy equipment and consumption, based on uninflated energy rates, for the operating area are summarized below:

Capital costs* = $86.79/1000 cu ft

Yearly maintenance and electricity costs* = $12.19/1000 cu ft

Annual costs* = $21.75/1000 cu ft

* Power level = 0.138 KW/cu ft

For the mechanized area, which is a humidity controlled, air-conditioned, automated warehouse facility, cost estimates can be read from Figures 36, 37, and 38. To use the charts, select the material handling equipment, lighting, and HVAC equipment for the zone and compute the installed power level in kilowatts per cubic foot. Then, enter Figure 36 for capital costs, Figure 37 for uninflated yearly maintenance and energy costs, and Figure 38 for the resulting annual costs.

Costs for the general storage area, which is a low volume flow, ventilation only, bulk storage area, are shown in Figures 39, 40, and 41. These figures are used in the same manner as those for the mechanized area.

It is recommended that cost changes due to changes in building geometry be evaluated as outlined above. Use of the values for overall building costs in dollars per 1000 cubic feet presented in Tables 149 through 162 is limited to those applications where the proportional share of operating area volume, mechanized area volume, and general storage area volume, and power levels for these areas, remains equal to those factors assumed as a basis of this study.

Sensitivity to Climate. Part of the EATG work request included the evaluation of system cost differentials associated with locating the facility in the following geographic regions: Harrisburg, Pennsylvania; Oklahoma City, Oklahoma; Los Angeles, California; and Oakland, California. GCE-76S made this evaluation by substituting appropriate weather data into the ECUBE energy analysis simulation. For this study the installed system equipment was held constant using the equipment selected for the Norfolk, Virginia geographic region; however, capital costs for the HVAC equipment were adjusted from the Norfolk values based on the proportional differences in HVAC block loads.

Yearly energy and maintenance costs were calculated from the kilowatt consumption and equipment operating hours data produced by the ECUBE simulation. The energy costs were based on $0.0441 per kilowatt-hour which is the same electricity rate used to evaluate the costs in the Norfolk, Virginia area. Actual electricity rates do vary throughout the country and would change the cost estimates projected in the same manner as differing costs in the Norfolk area would change the results for that region as discussed in the "Energy System Selection" section of this report. However, the purpose of this investigation was to determine the differential costs

related to climatic changes; therefore, the cost of electricity was held constant. Percentage differentials calculated in this study can be modified to reflect the geographical differences in projected electricity costs by conducting a follow-on study into projected electric rates.

To show the cost differentials due to the climatic changes between the five geographic regions studied, HVAC system capital costs, yearly energy and maintenance costs, and annual value costs were computed for each site. These costs were then converted to percentage differentials. The annual cost differences were also compared to the total energy systems costs for the Norfolk region to evaluate the sensitivity of the overall costs to changes in climate. Table 164 shows the resulting percentage differentials.

TABLE 164

REGIONAL COST DIFFERENTIALS

(PERCENT)

	OKLAHOMA CITY	HARRISBURG	LOS ANGELES	OAKLAND
HVAC Capital Costs	+4.4	-1.2	+1.2	-3.5
HVAC Yearly Energy And Maintenance Cost	+20.0	-25.0	+19.0	-31.0
HVAC Annual Value	+8.5	-7.5	+5.5	-11.0
Internal Energy Systems Annual Value	+1.9	-1.8	+1.4	-2.5

Evaluation of the cost differentials given in Table 164 shows that while there are significant differences in the HVAC energy requirements for the various geographic regions, the overall Internal Energy systems costs vary by less than 2.5 percent from the values established for the Norfolk, Virginia region; therefore, these values can be utilized with reasonable accuracy for all regions studied by following the procedures outlined in the preceding sub-section of this report.

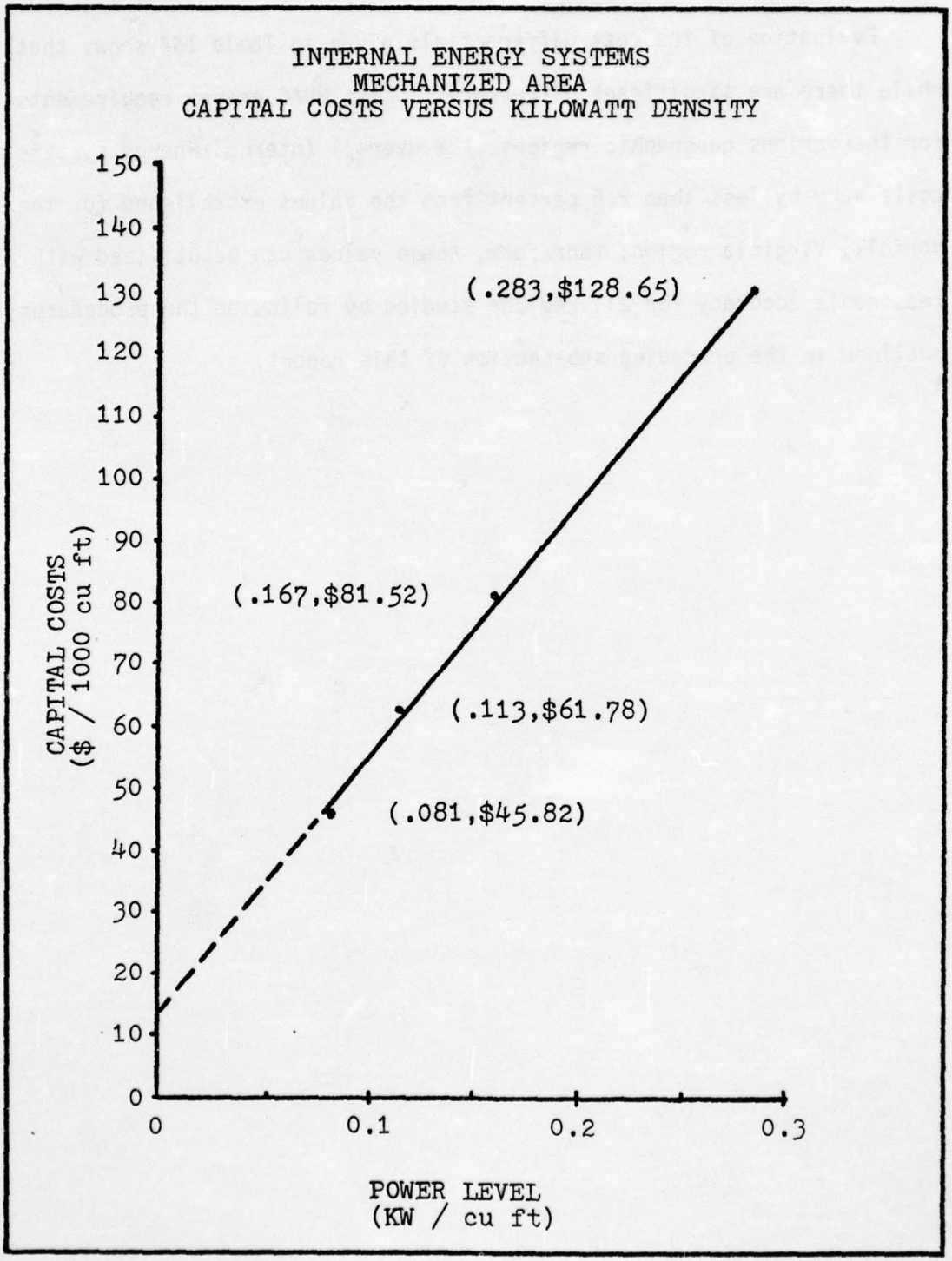


FIGURE 36 MECHANIZED AREA
CAPITAL COSTS VERSUS KILOWATT DENSITY

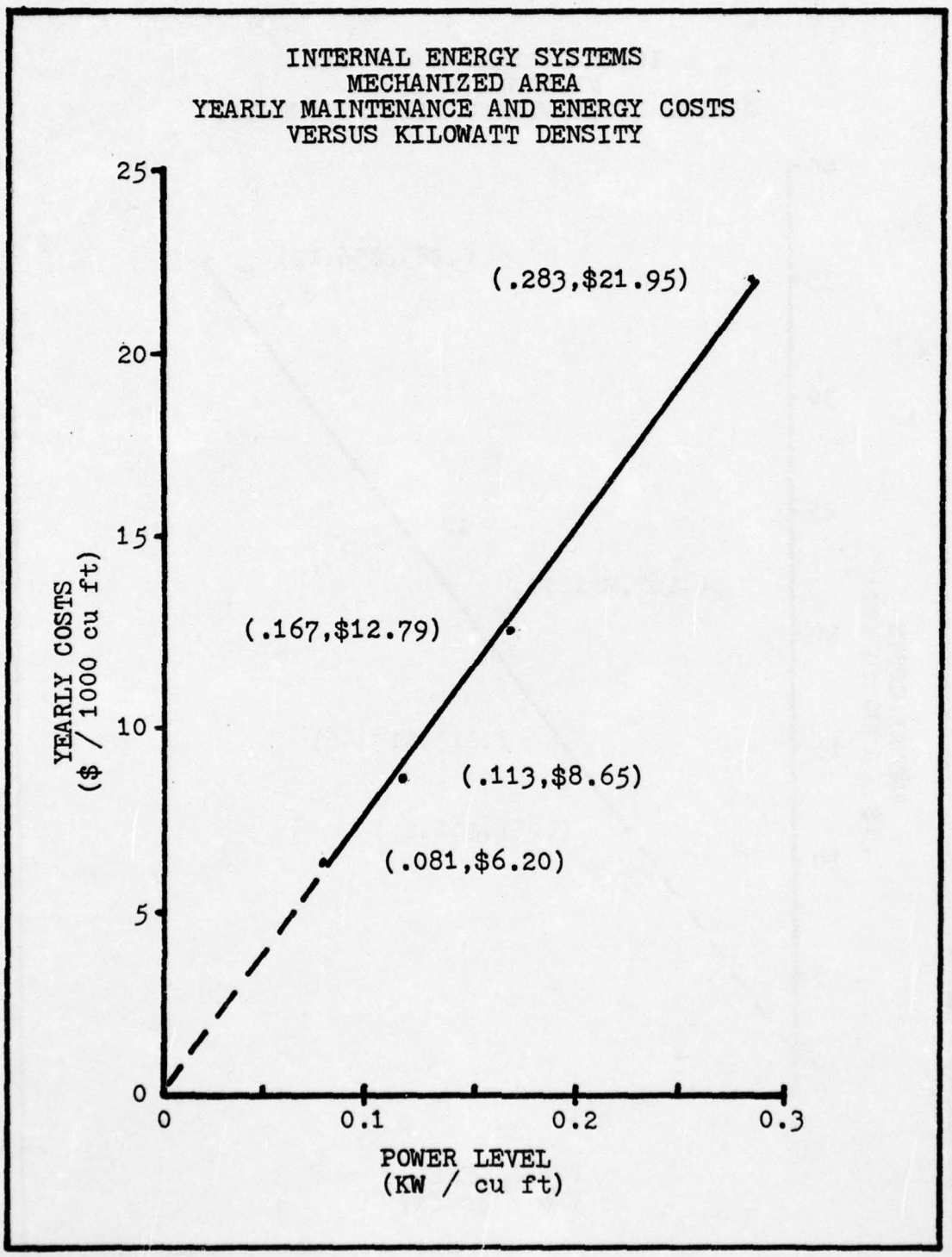


FIGURE 37 MECHANIZED AREA
YEARLY MAINTENANCE AND ENERGY COSTS
VERSUS KILOWATT DENSITY

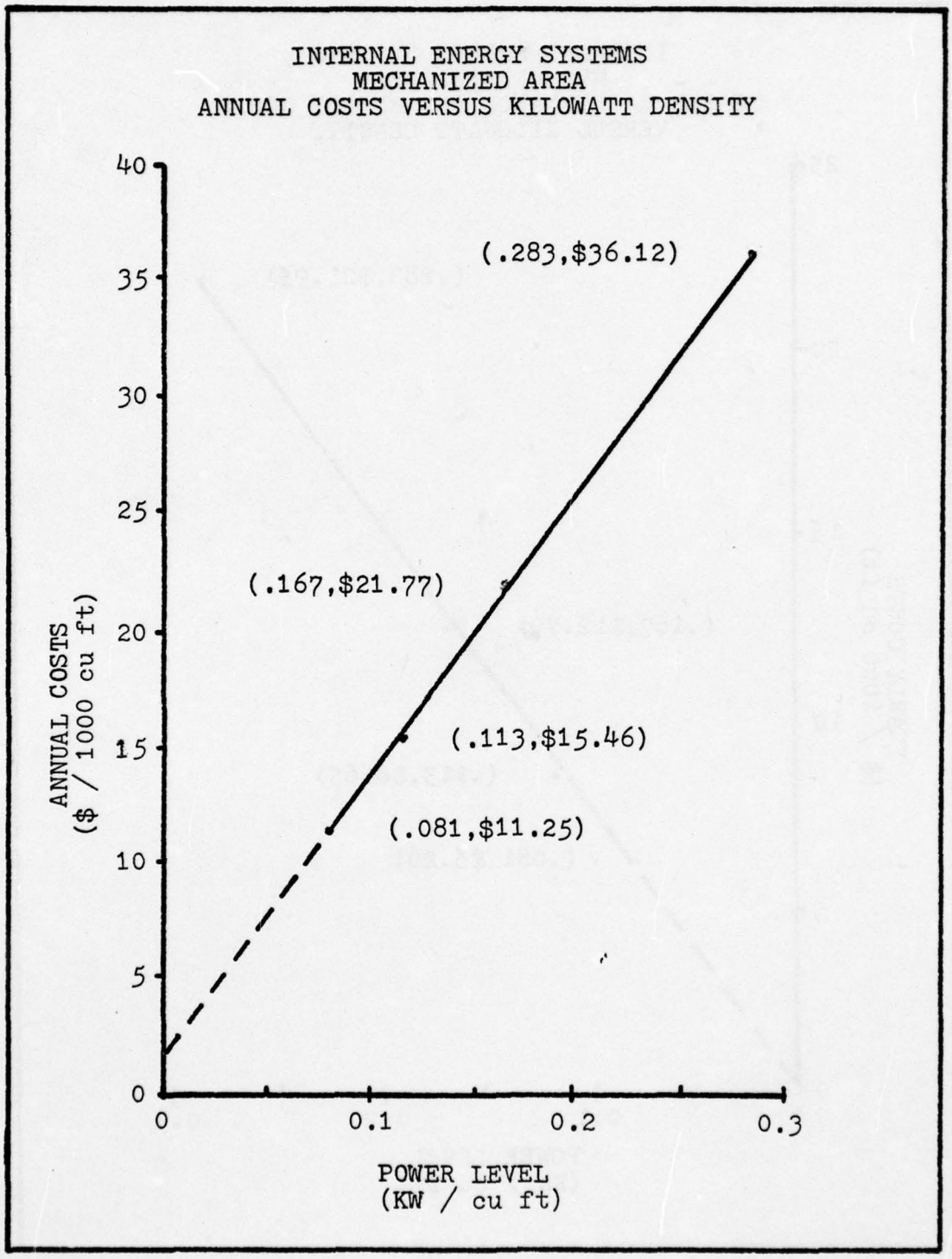


FIGURE 38 MECHANIZED AREA
ANNUAL COSTS VERSUS KILOWATT DENSITY

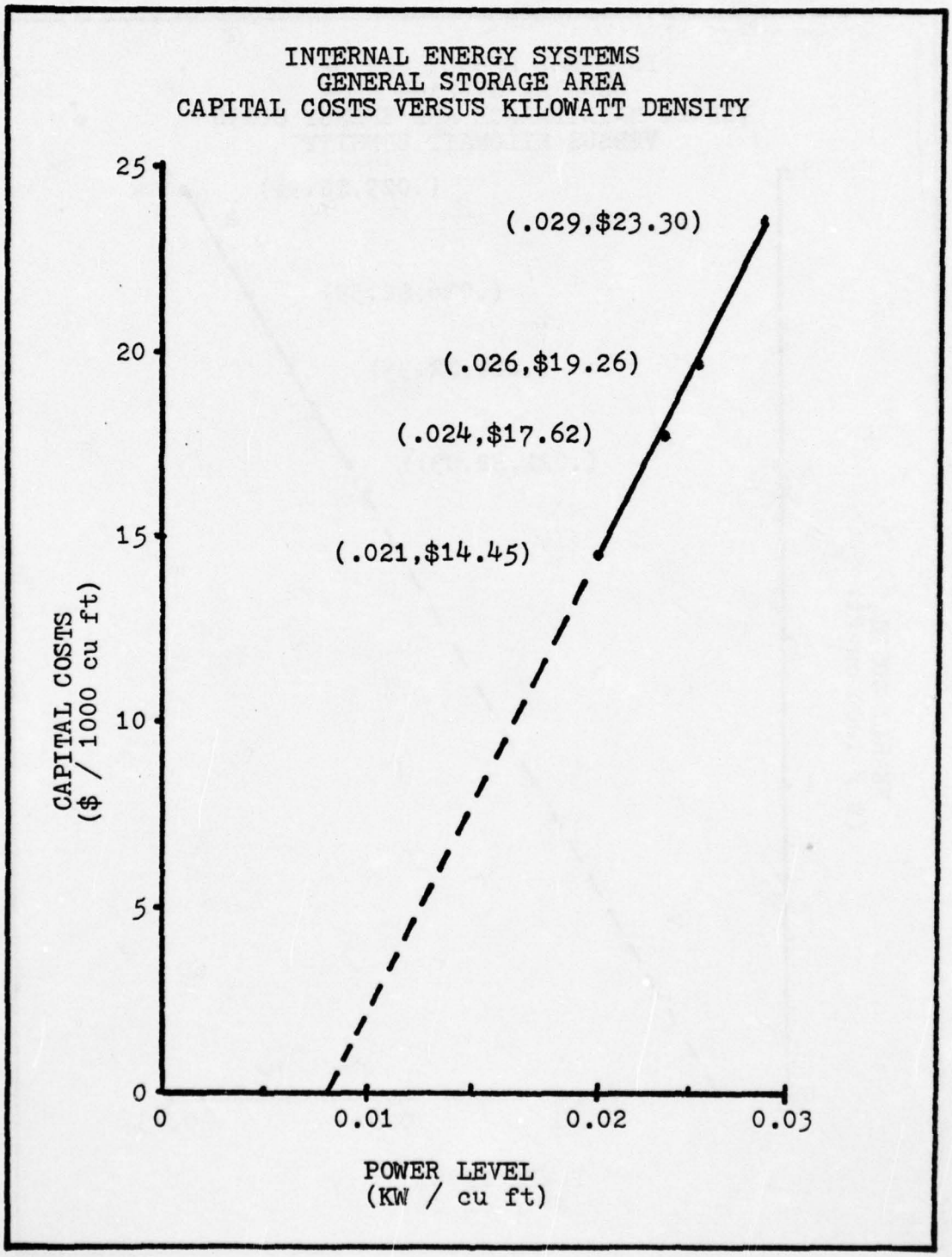


FIGURE 39 GENERAL STORAGE AREA
CAPITAL COSTS VERSUS KILOWATT DENSITY

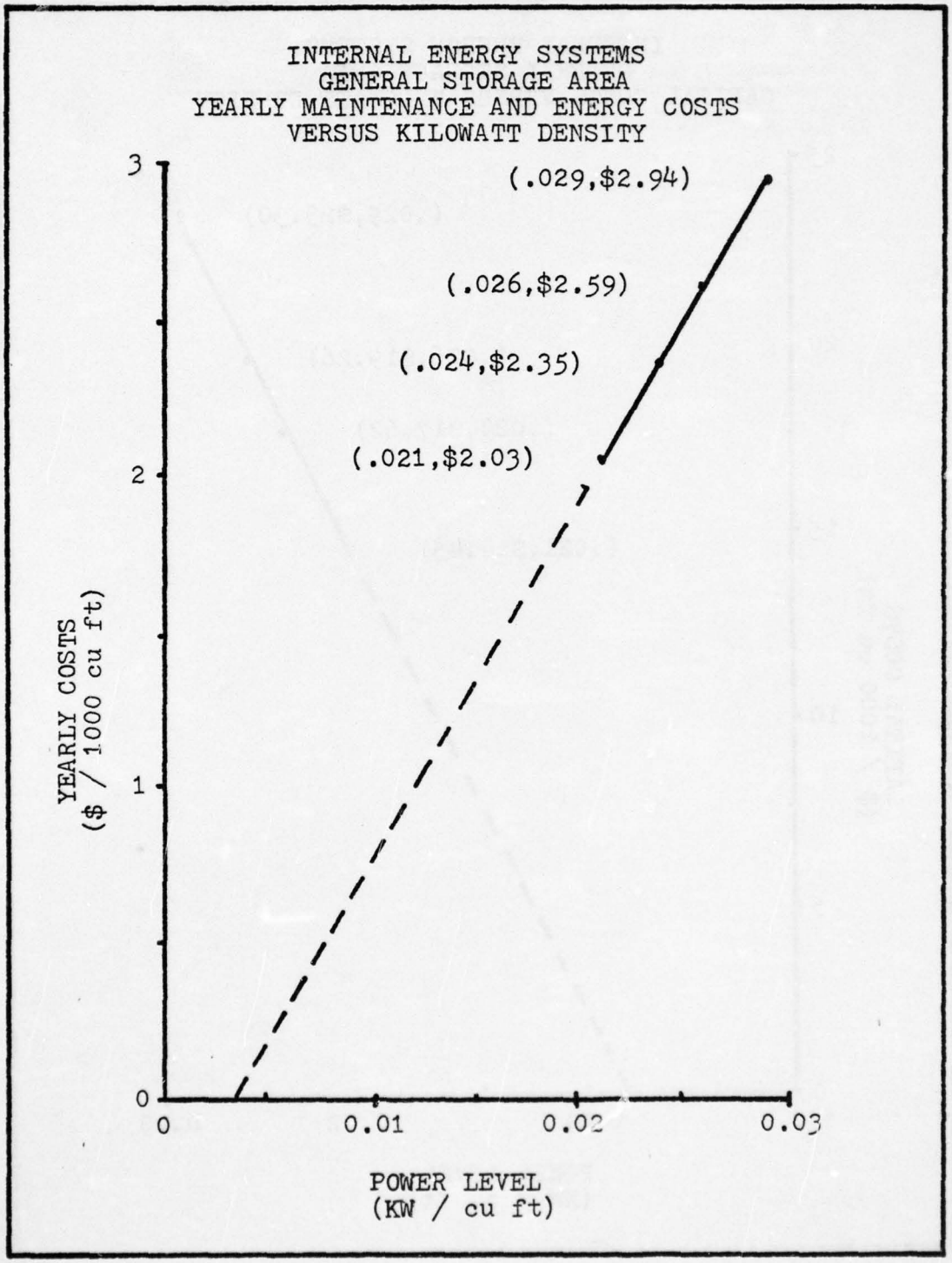
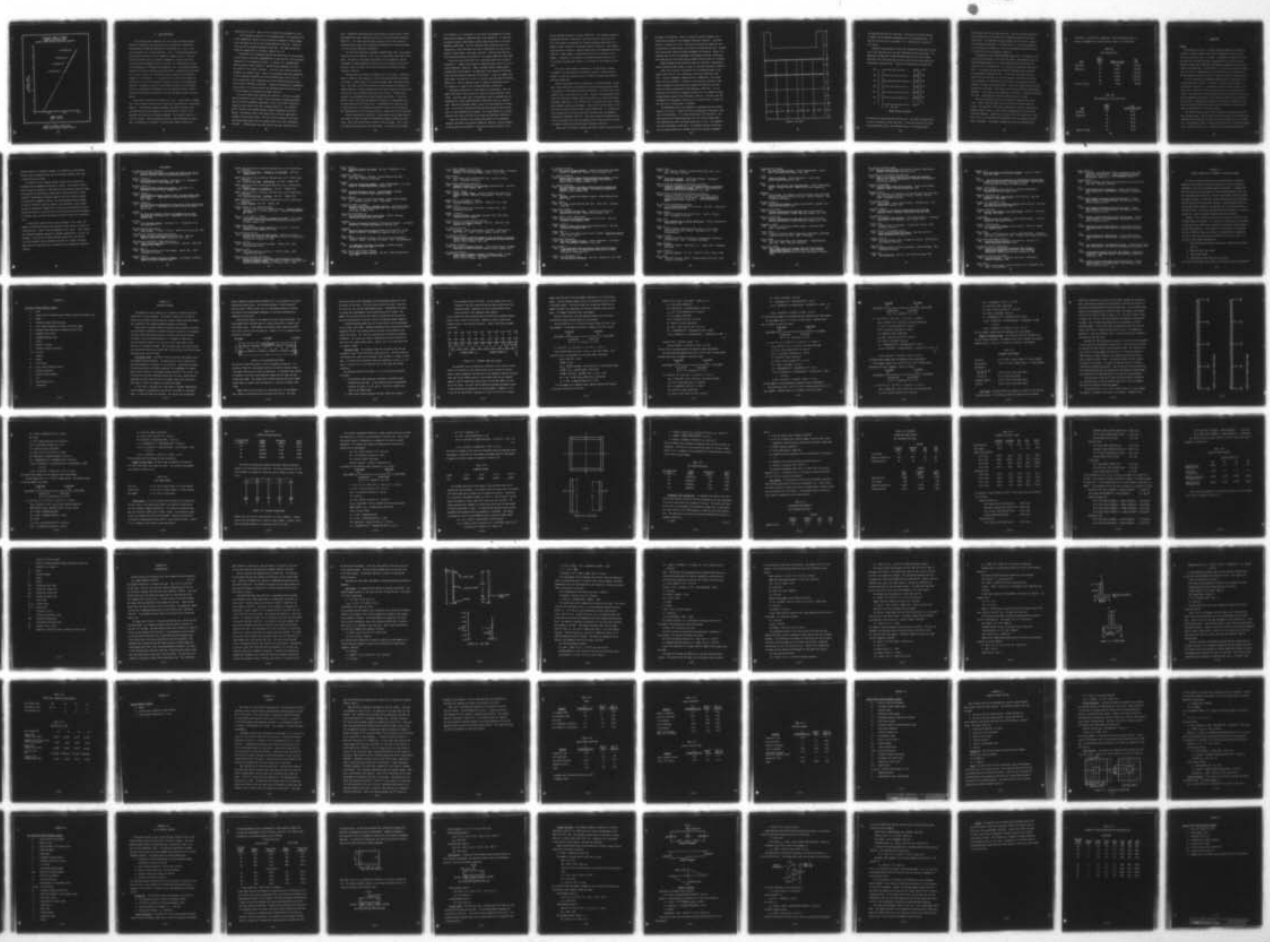


FIGURE 40 GENERAL STORAGE AREA
YEARLY MAINTENANCE AND ENERGY COSTS
VERSUS KILOWATT DENSITY

AD-A031 384 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 13/2
A GENERAL WAREHOUSE MODULE CONCEPTUAL DESIGN AND COST ANALYSIS.--ETC(U)
SEP 76 R T ALEXANDER, T J CARMICHAEL

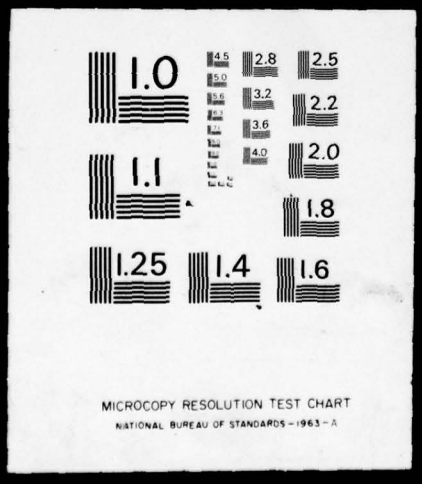
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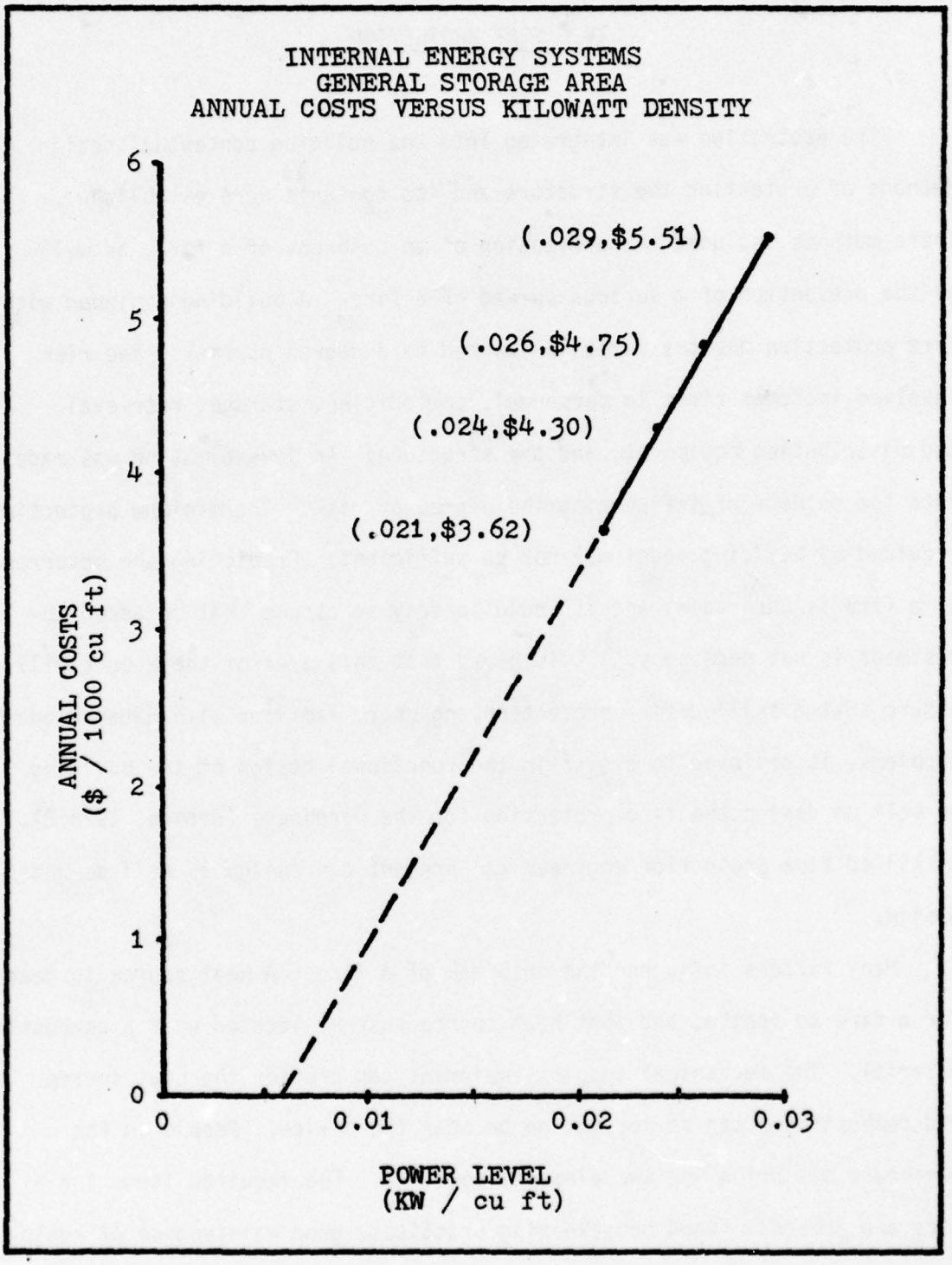


FIGURE 41 GENERAL STORAGE AREA
ANNUAL COSTS VERSUS KILOWATT DENSITY

IV. FIRE PROTECTION

Fire protection was integrated into the building conceptual design. Methods of protecting the structure and its contents were established. These methods included the prevention of an outbreak of a fire, as well as the prevention of a serious spread of a fire. A building equipped with fire protection devices is still exposed to a degree of risk. The risk involved includes risks to personnel, commodities, storage, retrieval, and distribution equipment, and the structure. An investigation was made into the methods of influencing the degree of risk. The minimum protection required by building codes may not be sufficient. Predicting the occurrence of a fire is uncertain, and it would be easy to assume that an added investment is not necessary. It is hoped that this area of the report will insure that a skilled fire protection engineer, familiar with warehousing problems, is employed to assist in the functional design of the building as well as design the fire protection for the warehouse (Jenson, 1975:8). A skilled fire protection engineer can prevent overdesign as well as underdesign.

Many factors influence the outbreak of a fire. A heat source is needed for a fire to ignite, and that heat source must be located near a combustible material. The mechanical support equipment can provide the heat source and combustibles can be located on or near the device. People in the warehouse can bring the two elements together. The required items for a fire are present. Good housekeeping practices, good maintenance of equipment, and education of personnel will contribute towards reducing the

possibility of a fire. There is still a chance of an outbreak of a fire.

A fire spreads up and out in a fan shaped pattern. The combustibility of the commodities stored in an area and the arrangement of those commodities influence the rate of fire spread (McKinnon, 1976:5-2). Smoke and toxic gas may be produced (McKinnon, 1976:1-19). The smoke and gas may affect the capabilities of personnel fighting the fire.

The National Fire Protection Association (NFPA) serves as the watchdog of the industry, publishes recommendations of good practice, and sets design standards for fire protection systems. In general, the recommendations herein conform to NFPA standards. Subdividing the warehouse can limit the spread of fire, smoke, and gases. Fire walls were used to divide the warehouse into smaller areas. Areas in the warehouse containing commodities of low or moderate combustibility must be 40,000 square feet or less in size, except depot level warehouses can contain 80,000 square feet within the fire walls (AFM 88-15, 1975:A24). Storage of noncombustible commodities can be placed in fire areas greater than 100,000 square feet and the size is not considered to be excessive (Factory, 1967:7-1).

Fire walls require both strength and stability. Sufficient strength must be available to resist impact loads from material handling equipment. The walls must be capable of remaining in place if the steel framing collapses on either side of the walls (Factory, 1967:7-3). The "Interior Walls" section of this report contains further information on the wall design. The material used in the construction of the wall must have a suitable fire resistive rating. The fire resistive rating of fire walls containing 40,000 square feet of storage area was four hours (AFM 88-15, 1975:A24). A 20,000 square foot area required two hour ratings for the

walls. Warehouses containing high piled storage, or rubber tires or other high combustible items, required six hour fire resistive ratings (Factory, 1967:7-2). A six hour fire resistive rating was used in this analysis. Concrete masonry blocks with an effective thickness of 9.9 inches provided a six hour rating (McKinnon, 1976:6-65).

The fire areas contained a maximum of 80,000 square feet. Many factors affect the rate of spread of a fire. This in turn affects the size of fire areas. The physical and chemical properties of the commodities and the arrangement of those commodities affect the rate of spread of stored commodities, width of aisles, size of piles, and use of pallets and racks (McKinnon, 1976:5-2).

Ceiling height can affect the prudent size of fire areas. Structures made of slotted or solid shelves, or open racks whose bottoms are blocked by pallets, in effect zone off an area and prevent water from reaching the fire. Such areas will utilize sprinklers installed under the shelves for added protection. General storage areas with items stacked into large piles, by necessity, have sprinklers installed at the ceiling. Portable rack storage is also protected by ceiling installed sprinklers. A fire that ignites close to the floor may develop and spread to a large degree prior to being sensed at the ceiling level. A combination of a large area and a high ceiling will allow greater dissipation of heat, and a fire may be well developed prior to activating sprinklers installed at the ceiling level.

Curtain boards may be installed. Curtain boards can be constructed of sheet metal or other substantial noncombustible material (McKinnon, 1976: 2-29). They limit the horizontal spread of heat and smoke. This in turn will speed up the operation of the sprinklers. For these curtain boards

to be effective, it is necessary to vary their size depending on ceiling height and the degree of combustibility of the commodities. A high roof may require curtain boards down to within eight to ten feet of the floor (McKinnon, 1976:2-29). This can interfere with the desired use of the storage area. Roof ventilators are used in combination with the curtain boards to remove smoke, toxic gases, and heat. Existing ventilators for ventilating and cooling can be used for this purpose (McKinnon, 1976:2-29).

Fire walls only contain the fire. Some other means must be used to extinguish it. Water is the primary extinguishing agent used in fire protection (McKinnon, 1976:6-5). Foams, including protein foaming agents, fluoroprotein foaming agents, low temperature foam, aqueous film-forming foam, and high expansion foam were investigated. It does not appear that these agents are practical for use in a general warehouse module (McKinnon, 1976:13-11). They are generally used in industrial processing areas or for protection in areas of fuel storage (McKinnon, 1976:13-11).

The general application of Halon gases was investigated. They are agents that leave little corrosive or abrasive residue (McKinnon, 1976: 13-20). They have major uses in protecting electrical equipment and can be applied in a fixed system (McKinnon, 1976:13-21) such as a computer room. The entire enclosed volume is used in the determination of system size. It can also be used by directing the gas nozzles on each surface that is to be protected by the system. This second method is a far more expensive and a less efficient use of Halon gas (McKinnon, 1976:13-21).

Water was selected as the extinguishing agent for the warehouse. Automatic sprinklers are essential (McKinnon, 1976:5-3), and the concept of 100 percent area protection is necessary if water sprinklers are to

provide adequate protection (Factory, 1967:13-2). The warehouse concept as designed by GCE-76S is heated and a wet pipe sprinkler system was used. A wet pipe system is preferable for storage warehouses where there is no danger of water freezing in the system (McKinnon, 1976:5-4). High temperature sprinklers instead of ordinary temperatures are recommended (McKinnon, 1976:5-4). Water damage is reduced with little or no increase in fire damage. A reduction in the number of sprinklers operated during a fire is realized, and more water pressure is available for the operating sprinklers.

The rate of water demand is dependent on storage height, storage arrangement, and the design of the sprinkler system. Careful design is needed to insure that sprinklers are not robbed of needed water pressure (McKinnon, 1976:5-8).

High closely packed piles of commodities can create problems. Heights over 15 feet shed water and the bottom of the pile may not get wet enough to extinguish a fire quickly (McKinnon, 1976:14-8). Sprinkler water easily reaches a fire on the exterior of a pile. Once the fire progresses to the point that the piles collapse, then the sprinklers can control the spread (McKinnon, 1976:14-8). It is difficult for the ceiling sprinkler to direct water through narrow vertical spaces. These vertical spaces create a chimney effect and the fire can quickly travel through them. It is good practice to keep piles as narrow as possible consistent with the warehouse configuration (McKinnon, 1976:5-3). Main aisle space should generally not be less than eight feet wide, and adequate cross aisles should be provided for manual fighting and building egress (McKinnon, 1976:5-3).

Water must be provided to hydrants and hoses located inside the building

for manual fire fighting. There is a need for exterior hydrants to be located near entrances to the warehouse (McKinnon, 1976:5-4). Sprinklers alone will not put out a fire. They serve to contain and reduce the rate of spread until further action can be taken to extinguish the fire. Portable fire extinguishers should be placed throughout the warehouse. Manual fire fighting, both by the fire department and warehouse personnel selected for fire fighting, will contribute greatly towards holding losses to a minimum.

Alarms actuated by the sprinklers should be installed. Additionally, alarms actuated by heat, smoke, or both, are advisable (McKinnon, 1976:5-5).

A one story structure is preferable for a warehouse because of the greater efficiency for fire fighting and ventilation (McKinnon, 1976: 5-2). Storage arrangement, combustibility of commodities, and storage height must be considered. Disastrous fires have been recorded in warehouses equipped with sprinklers where combustible materials have been stored at heights approaching 50 feet (McKinnon, 1976:14-8). In-rack sprinklers are required for adequate protection for all commodities where storage heights exceed 25 feet (McKinnon, 1976:5-6). Therefore, GCE-76S recommends that the general storage area not exceed 30 feet in height unless the use of fixed shelves is intended.

The operations area of the warehouse is separated from the storage areas by a fire wall. Figure 42 on the following page illustrates a plan view of the structure. All of the interior walls are fire walls. The areas enclosed are 79,200 square feet for 20 of the 24 storage areas. The remaining four areas are 39,600 square feet in size. This complies with the requirements of AFM 88-15. An expanded area may be justified, but not without knowing the intended contents and storage arrangement.

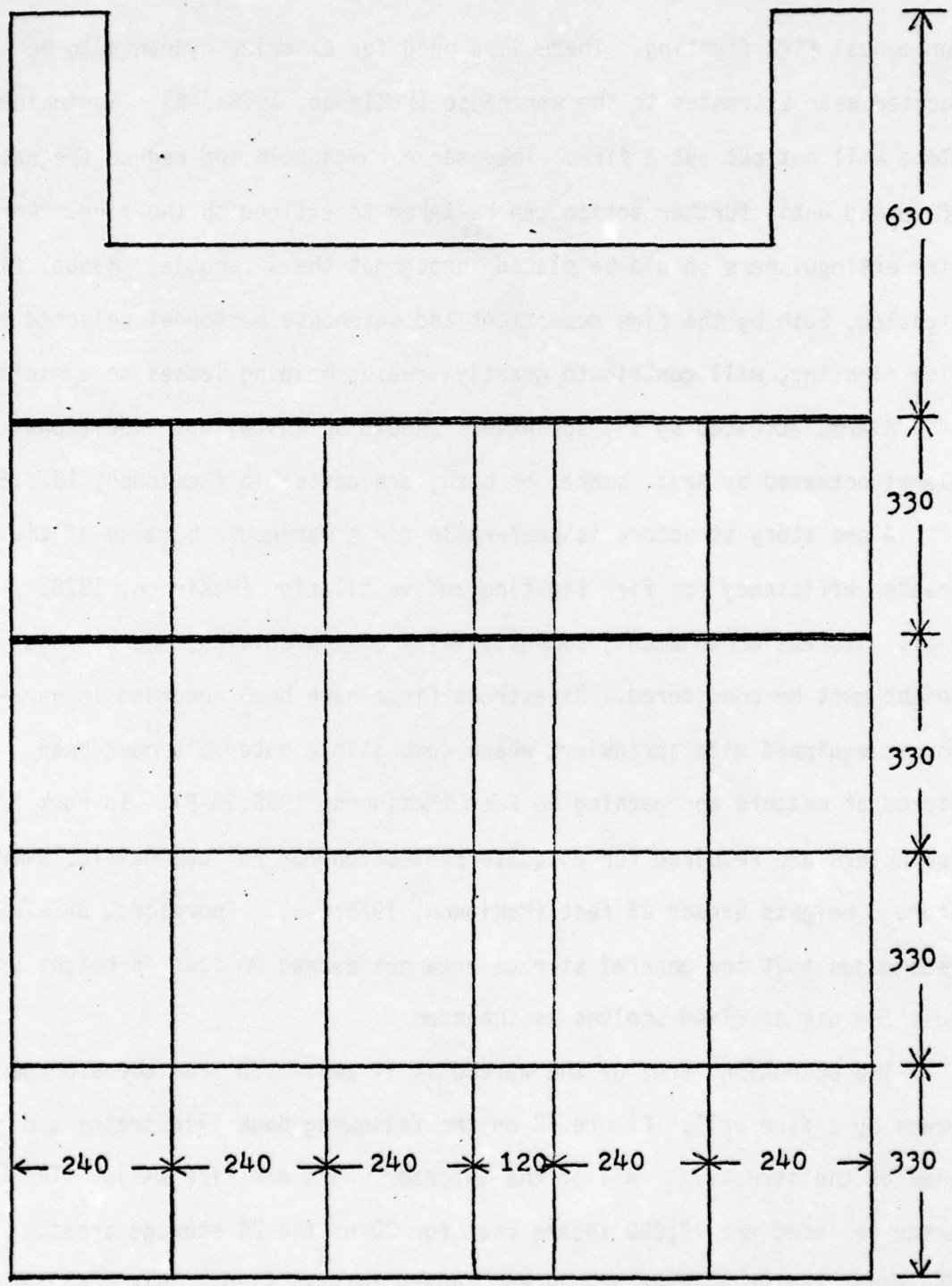


FIGURE 42 FIRE WALLS

The operating area was left undivided. It may be that further research is needed into the maximum recommended size in the operating area. The cost for the fire walls is provided in the "Interior Walls" section of this report.

Sprinklers were arranged so that each covered 100 square feet of floor area in the operating area, and were installed at the ceiling level. The mechanized storage area included 215,186 square feet of rack storage. Sprinklers were installed every ten feet vertically and every eight feet horizontally along the racks. Figure 43 illustrates the configuration.

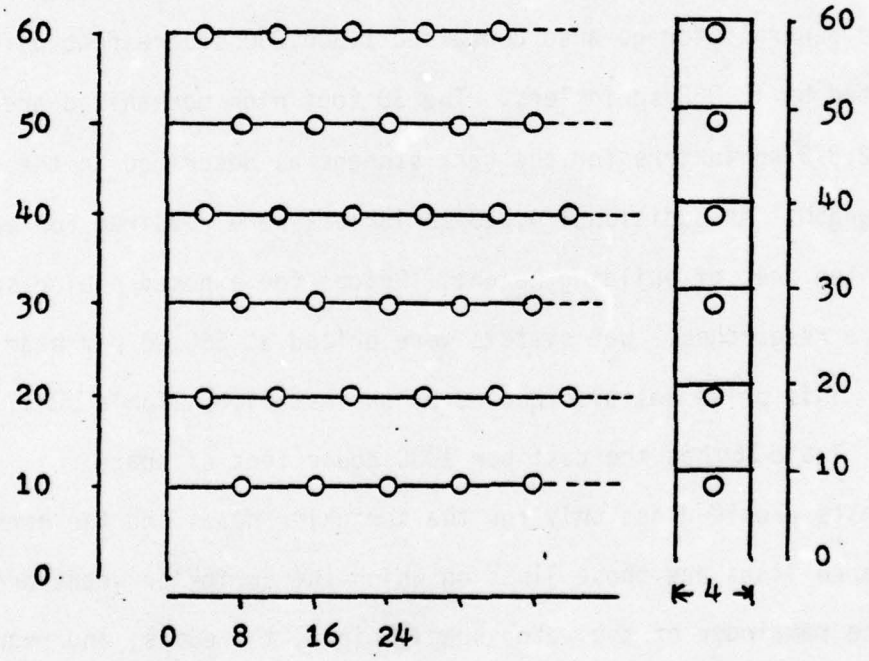


FIGURE 43 RACK SPRINKLERS

The racks were placed along the 330 foot wall, and 33,000 horizontal feet of rack is required for each rack level. A four foot rack and five foot aisle widths were used in the mechanized area. Bin storage covered

79,279 square feet of the mechanized area. Ceiling installed sprinklers were placed over this area and over the remaining portion of the mechanized area. The remaining area was assumed to be utilized for support of the mechanized equipment. No fixed shelves or racks were assumed to be in the general storage area. This ceiling height was therefore fixed at 30 feet for the fire protection analysis.

The operating area contained 464,400 square feet. The number of ceiling installed sprinklers in this area was 4,644. The mechanized area contained 435,600 square feet, of which 220,414 square feet had ceiling sprinklers for fire protection. This required an additional 2,204 sprinklers. The general storage area contained 1,306,800 square feet which was protected by 13,068 sprinklers. The 30 foot high mechanized area required 12,375 sprinklers for the rack storage as described in the previous paragraph. An additional 4,125 sprinklers were required for each additional ten feet of building height. Prices for exposed piping sprinkler systems were researched. Wet systems were priced at $60.00 per head (Means, 1975:200). This price was also quoted by an installer. Table 165 illustrates the costs. Table 166 has the cost per 1000 cubic feet of space.

The costs provided are only for the sprinkler heads and the branch lines. Branch lines are those lines on which the sprinkler heads are placed. The remainder of the water supply pipes, the pumps, and required backup storage of water, if any, should be determined by a skilled fire protection engineer. Optimum size of supply lines and location of risers, main lines, are influenced by the combustibility of the items stored and their arrangement. The numbers presented here may be determined to be

sufficient, or oversized or undersized. They are presented only as a typical arrangement for a cost influence factor for the structure.

TABLE 165

FIRE PROTECTION ($)

AREA	BLDG HEIGHT (FT)	NUMBER OF HEADS	COST ($)
Operating	30	4,644	278,640
Mechanized	30	14,579	874,740
	40	18,704	1,122,240
	50	22,829	1,369,740
	60	26,954	1,617,240
General Storage	30	13,068	784,080

TABLE 166

FIRE PROTECTION ($/1000 CUBIC FEET)

AREA	BLDG HEIGHT (FT)	COST ($/1000 CUBIC FEET)
Operating	30	20.00
Mechanized	30	66.94
	40	64.41
	50	62.89
	60	61.88
General Storage	30	20.00

V. CONCLUSION

Summary

The engineering study of a general warehouse module has resulted in a number of related concepts which can be integrated to provide a total facility meeting the needs of the EATG. Evaluation of systems which would best meet the projected functional requirements of the facility, while achieving economy and incorporating contemporary equipment and structural systems, was emphasized. The end result is not so much a specific building cost, but rather a comprehensive set of data which can be interpreted to provide engineering costs related to a range of functional configurations.

The civil engineering development demonstrated the importance of including engineering criteria, in addition to logistics requirements, in site selection decisions. In evaluating various structural schemes, consideration of internal flexibility and possible facility expansion was included. The braced steel frame structure selected provided this flexibility while accommodating the specific load conditions applied for the Norfolk, Virginia area. Subsequent development of cost data was presented so that the various options defined by EATG could be extracted in terms of total cost for any section of a selected facility.

The internal energy systems study included both commercial power and total energy systems. Both of these options were shown to be feasible and, depending on the selected facility design, either system may be cost effective. The governing factor in energy system selection will be the projected costs of electricity and fuel. Where the resulting cost differential is

not significant, the evaluation of material handling equipment and personnel requirements not included in this study, may become a determining factor. The analysis showed that the cost of internal energy systems was most sensitive to projected energy consumption. Structural geometry was found to be less significant in determining energy costs.

An adequate, yet economic, fire protection system could not be selected without detailed knowledge of commodity mix and storage arrangement. However, critical fire protection factors that must be considered were investigated. Representative costs were provided for a typical fire extinguishing system. It must be stressed that for the final design, the slection of fire protection systems should be undertaken only after storage layout and commodity mix has been defined in detail.

Although no attempt has been made to design or cost specific details, the resulting concepts are considered to give a sound evaluation of the feasibility of practical state-of-the-art systems, the sensitivity of the overall facility to the selection of various systems, and an input of cost magnitude to the complete DODMDS study. The application of the results obtained within the limits prescribed should result in a valuable contribution to the final selection of an economic and functionally optimized facility.

Relationship to Industrial Practice

One of the guidelines set by EATG for this study was that all results be based upon state-of-the-art technology which reflects contemporary industrial practice. GCE-76S made a concerted effort to follow this request. The results found in this report do meet this criteria in most cases. Cost data was based on the current market prices for material and

equipment, the price of installation, and where appropriate, the projected yearly costs for maintenance and energy. These costs were obtained from current industrial estimator guides and/or directly from the manufacturers. Exceptions to current industrial practice were made where DOD mission requirements, specified by EATG, either exceeded or differed from typical civilian requirements.

The GCE-76S Civil Engineering results were based on a steel framed structure, which represents common industrial practice. The design was developed to meet the requirements of the American Institute of Steel Construction Specifications and Code, the American Concrete Institute Code, and the National Building Code. One contemporary practice of special interest was the selection of tilt-slab panels for the exterior wall. This type construction provides the most cost effective wall section, improves security, and reduces maintenance. Two structural requirements specified by EATG did exceed the typical construction practices found in civilian warehouses. EATG specified that the minimum column spacing in both directions be set at 60 feet. Normally, column spacing in at least one direction would be limited to no greater than 30 or 40 feet. The increased column spacing specified by EATG to allow for handling large items did result in the costs for the open web, truss roof system being higher than for systems with closer column spacing. The second parameter which exceeded standard industrial practice was the specification of floor loadings of 1000 pounds per square foot and greater. Typical warehouse floor loadings range from 250 to 500 pounds per square foot. Cost differentials associated with the higher floor loadings are not significant if soil with adequate

bearing capacity is available; however, soil conditions in the Norfolk, Virginia area are generally poor and the increased loadings could cause a significant cost increase.

The results in the "Internal Energy" section of this report were developed using contemporary practice as a guide. The electrical distribution system was designed in compliance with the National Electrical Code. The selection of high pressure sodium vapor lighting reflects a current industrial trend showing increased usage of this cost effective system. The selection of commercial power as the primary energy source conforms to typical industrial practice; however, the evaluation of total energy systems as economically competitive is verified by the existence of total energy applications in such facilities as the Sears Distribution Warehouse at Columbus, Ohio, and the International Harvester Factory at Springfield, Ohio.

To develop the results and cost data presented in this study, the members of the GCE-76S study group contacted a wide variety of industrial representatives, listed in the bibliography to this report. These individuals represent warehouse operators, equipment manufacturers, and facility designers. With the aid of these technical authorities, the GCE-76S class has produced a design concept evaluation for a general warehouse module which is based upon and in compliance with contemporary industrial practice.

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APPENDIX C-1

ECONOMIC COMPARISON OF ALTERNATIVE STRUCTURAL SCHEMES

In order to provide some basis for the selection of a structural scheme for the building, a preliminary analysis of various systems was undertaken in the initial planning stage of the project. Although total cost was the controlling parameter in the elimination process, other factors considered were feasibility, flexibility and gross structural weight. For example, timber or reinforced concrete structures were not considered feasible because of the long spans required. Heavy structures were considered undesirable because of the apparent poor soil bearing capacity in the Norfolk area. Flexibility was considered best achieved in a structural system which could be repeated throughout the entire building.

Because of the preliminary nature of this analysis, only the 30 foot building height was examined. The analysis was limited to roof structures as the overall roof weight would control the significant loads applied to columns and foundations. Wind loads were not considered at this stage. The use of 1975 cost data was selected as a common base for comparison of costs as 1976 cost data was not available at this early state. The structural roof systems analyzed were:

1. Wide flange beam and girder system with standard open web steel purlins.
2. Open web steel truss system.
3. Space frame systems.
4. Prestressed concrete beam and slab system.

Cost data for the space frame systems was provided by Unistrut Corporation

(Shaw, 1976). All other systems were costed from Means Building Construction Cost Data 1975. As each system analyzed had comparative advantages and disadvantages an attempt was made to evaluate these in terms of cost benefit. Particular factors considered were:

1. Wall height - The depth of the roof structure was assumed to be an added height above 30 feet and the increased perimeter wall height was costed.
2. Insulation - Structural systems such as prestressed concrete slab provide part of the required roof insulation and this was subtracted from the total insulation cost.
3. Roof deck - Roof deck weight varied for the structural systems investigated and this variation was reflected in the cost comparison. For the prestressed concrete structure no metal decking was required.

An estimate of total column live plus dead load was made to show the possible effect on foundation requirement. This, and a summary of resulting cost is shown in the following table.

TABLE C-1-1

SUMMARY OF COSTS FOR STRUCTURAL ROOF SYSTEMS

	WIDE FLANGE SECTIONS *	OPEN WEB TRUSS *	4 FT SPACE FRAME **	5 FT SPACE FRAME **	PRESTRESSED CONCRETE *
Materials & Install	$7,845,300	$3,783,900	$6,708,500	$5,884,600	$7,419,000
Additional Wall	$ 68,400	$ 136,800	$ 74,800	$ 95,500	$ 76,000
Insulation Savings	0	0	0	0	$- 225,000
Roof Decking	$2,025,000	$2,025,000	$1,350,000	$1,350,000	0
Total	$9,940,000	$5,950,000	$8,133,000	$7,330,000	$7,270,000
Column Load, Kips	141	123	128	126	290

* (Means, 1974)

** Unistrut 1975 prices (Shaw, 1976)

APPENDIX C-2

Structural Framing Appendix Symbols

A - Area

b - Actual width stiffened and unstiffened compression elements (in)

b' - Width

d - Distance between centroidal axes

Fa - Axial stress permitted in absence of bending moment

Fb - Bending stress permitted in absence of axial force

f_a - Computed axial stress

f_b - Computed bending stress

h - Height

IZ - Moment of inertia

K - Effective length coefficient

k-in - Kip-inch

l - Length

M - Moment

P - Axial force

Qs - Axial stress reduction factor

r - Radius of gyration

S - Elastic section modulus

T - Ton

t_w - Web thickness (in)

Δ - Deflection

APPENDIX C-2

STRUCTURAL FRAMING

The objective of this analysis was to develop a feasible structural scheme for a 50 acre warehouse. The scope of analysis was limited to assuring the proposed structure met the various building code requirements while complying with standard engineering design restrictions.

Observation of current industrial practice and an economic evaluation were performed to determine a suitable structural system for the warehouse. The steel column and framing system was the most cost effective based on Norfolk, Virginia design parameters. No attempt has been made to provide connection details or to vary the size of each frame so that they are all 100 percent loaded. Once the Warren truss and column system was selected the design was accomplished in three phases; preliminary frame, secondary frame, and main frame.

Preliminary Frame. The Warren trusses could have been modeled using the standard pinned end method. The application of such a model using the modern methods of connection is not realistic. High strength bolted, friction-type joints and welded connections are recommended for members where stress reversal is anticipated (Salmon, 1971:87). The initial loading conditions that were developed showed that the truss system would be subjected to stress reversal within the members due to the wind forces. Both types of joints are capable of transmitting moment.

If the truss is analyzed with fixed joints it becomes indeterminate with the degree of indeterminacy varying with the number of continuous spans. A fixed end model was selected. The analysis was accomplished

using a computer program entitled STRESS which is an acronym for Structural Engineering System Solver. The stiffness method of linear structural analysis used in STRESS solves a set of simultaneous equations relating the unknown joint displacement components to the known balanced force components at each joint.

Initially one frame six feet deep and 60 feet long was analyzed. The first members were selected based on a hand calculation of a Warren truss with pinned joints. These members and Loading 1 were loaded into STRESS with joints 2 and 12 as fixed supports. Figure C-2-1 is a graphical presentation of the model.

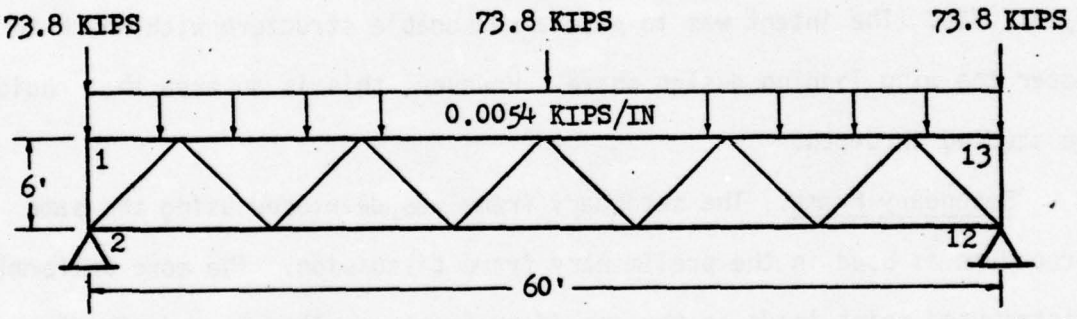


FIGURE C-2-1 PRELIMINARY MAIN FRAME

The analysis showed that joints 1 and 13 displaced horizontally. In a continuous frame this displacement would be resisted by adjacent frames. A new model containing four bays was developed. To introduce three degrees of freedom at the joints associated with supporting the frame, 30 foot columns were added. The columns were selected from the AISC axial loaded column tables to support 150 kips based on a K value of 1.0 (AISC, 1973: 5-138).

Member selection and analysis was continued until all the members were capable of withstanding the calculated axial forces. The force

distribution within the frame members was approximately symmetrical about the center of each span. The actual forces varied from span to span due to carry over, but each was approximately equal. Consideration was given to varying the frame members so that each would be fully loaded. The member force variation across the frame was uniform and did not provide any well defined point or section at which to change the member geometry.

A combined bending moment and axial force analysis was not performed at this stage of the study. Reference documents such as Gaylord and Urquhart suggested that the wind loading would be the most severe condition and control the design. This fact was substantiated by the thesis presented by GCE-75D. The intent was to have a reasonable structure with which to enter the wind loading design phase. However, this is an area that could be studied in depth.

Secondary Frame. The secondary frame was developed using the same procedure as used in the preliminary frame discussion. The more uniformly distributed point loads on the secondary frame resulted in a depth of three feet. For stability the secondary frame was supported at joints 1, 2, 22, and 23. Figure C- 2-2 is an elevation view of the frame and loading conditions.

The boundary condition for joints 1, 2, 22, and 23 were developed as follows:

1. The secondary frame system was considered a continuous frame supported every 60 feet. As such there would be no appreciable rotation of joints 1, 2, 22, and 23. They were assumed to be fixed in the STRESS model.
2. Under either loading condition the main frame which supports

the secondary frame will deflect. It was assumed that the deflection of the main frame would be the same at each end of the secondary frame. Therefore, the main frame deflection would have no effect on the secondary frame supports.

It was assumed that there would be vertical differential movement between joints 1 and 2 as well as 22 and 23. Therefore, joints 1 and 23 were allowed to move in the vertical direction. Joints 2 and 22 were assumed to be fixed.

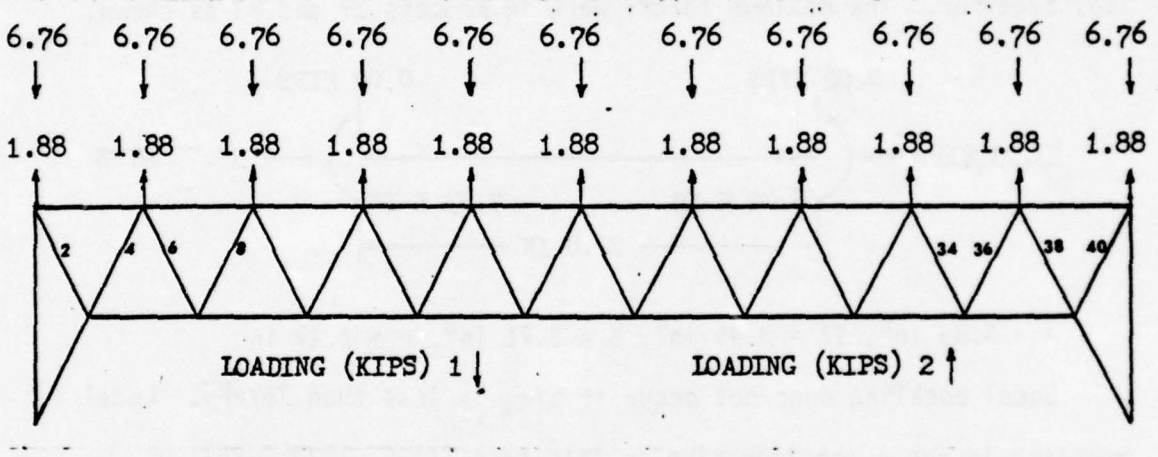


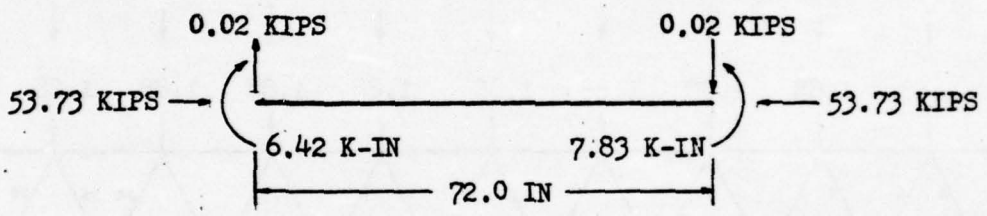
FIGURE C-2-2 SECONDARY FRAME AND LOADING

The secondary truss as modeled was subjected to only vertical forces. There is no variation of the frame relative to the structure's height. Based on these assumptions only one bay of the secondary frame was analyzed. After the initial STRESS analysis it was evident that the two diagonal members 1 and 41 transmitted larger forces into the web members at each end of the frame. The axial force differential between web members necessitated selecting two geometries for the web members. Members 2, 4, 6, 8, 34, 36, 38, and 40 were increased to a 3-1/2 X 3-1/2 X 3/8 in single

angles while the rest of the web members remained as 2 X 2 X 3/8 single angles. The two diagonal supports were also reinforced to 3-1/2 X 3-1/2 X 3/8 double angles. The revised frame was analyzed by STRESS and the members evaluated for compliance with the AISC combined stress requirements. All members satisfied these requirements.

Typical calculations using the combined maximum forces resulting from the most severe loading condition are presented.

The top chord was a 6 X 4 X 5/16 inch double angle with the 4 inch legs together. The maximum forces were in members 19 and 23 as shown.



$A = 6.05\ in^2$, $IZ = 8.45\ in^4$, $S = 2.71\ in^3$, $r = 1.17$ in

Local buckling does not occur if b/t_w is less than $76/\sqrt{Fy}$. Local buckling is not a consideration in this case (AISC, 1973:5-25).

$b/t_w = 4/0.3125 = 12.80$

$76/\sqrt{50} = 10.75$

$b/t_w > 76/\sqrt{Fy}$ Therefore, local buckling is a consideration when

$76/\sqrt{Fy} < b/t_w < 155/\sqrt{Fy}$ (AISC, 1973:5-115)

$76/\sqrt{50} < 4/0.3125 < 155/\sqrt{50}$, $10.75 < 12.80 < 21.92$

$Qs = 1.34 - 0.0047\ (b/t_w)(\sqrt{Fy})$ (AISC, 1973:5-115)

$Qs = 1.340 - 0.00447(12.80)(7.07) = 0.935$

For the member to be adequate under combined loading AISC formulas 1.6-1a and 1.6-1b must be satisfied.

Formula 1.6-1a $f_a/Fa + f_b/Fb(Cm/1 - f_a/Fe') \leq 1.0$

$Cm = 0.85$ (AISC, 1973:5-23)

$Fb = Qs(0.6)(Fy) = (0.935)(0.6)(50) = 28.05$ ksi

$f_a = P/A = 53.73$ kips$/6.05$ in$^2 = 8.88$ ksi

$K = 1.0$ (Salmon, 1971:266)

$Kl/r = (1.0)(720$ in$)/1.17$ in $= 61.54$

$Fa = 22.45$ ksi (AISC, 1973:5-87)

$f_b = M/S = 7.38$ k-in$/2.71$ in$^3 = 2.72$ ksi

$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(72/1.17)^2 = 39.35$

1.6-1a $8.88/22.45 + 2.72/28.05(0.85/1 - 8.88/39.35) = 0.502 < 1$

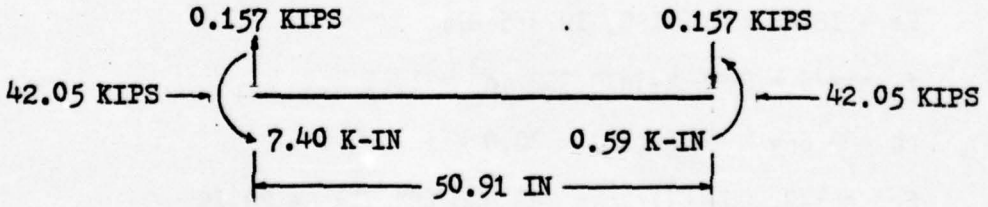
O.K.

Formula 1.6-1b $f_a/0.6Fy + f_b/Fb < 1.0$

$8.88/(0.6)(50) + 2.72/28.05 = 0.393 < 1.0$ O.K.

The top chord as presented meets the combined stress requirements.

The reinforced web members were 3-1/2 X 3-1/2 X 3/8 in single angles. Maximum forces were in members 4 and 38 as shown.



$A = 2.48$ in^2, $IZ = 2.87$ in^4, $S = 1.15$ in^3, $r = 1.07$ in

$b/t_w = 3.5/0.375 = 9.33 < 10.75$ O.K. (no local buckling)

$f_a = P/A = 42.05$ kips$/2.48$ in $= 16.96$ ksi

$Kl/r = (1.0)(50.91$ in$)/1.07$ in $= 47.60$

$Fa = 24.72$ ksi (AISC, 1973:5-87)

$f_b = M/S = (7.40$ k-in$)(1.15$ in$^3) = 6.43$ ksi

$Fb = 0.6Fy = (0.6)(50) = 30.0$ ksi

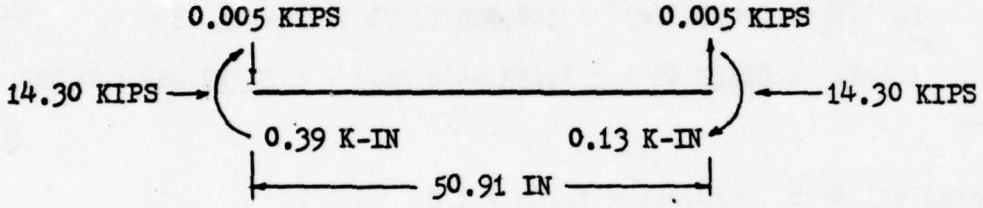
$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(47.60)^2 = 65.76$

1.6-1a $16.96/24.72 + 6.43/30(0.85/1 - 16.96/65.76) = 0.932 < 1.0$ O.K.

1.6-1b $16.96/30.0 + 6.43/30.0 = 0.780 < 1.0$ O.K.

The reinforced web members as presented met the combined stress requirements.

The web members were 2 X 2 X 3/8 in single angles. Maximum forces were in members 16 and 26 as shown.



$A = 1.36$ in^2, $IZ = 0.479$ in^4, $S = 0.351$ in^3. $r = 0.601$ in

$b/t_w = 2/0.375 = 5.33 < 10.75$ O.K. (no local buckling)

$f_a = P/A = 14.30$ kips$/1.36$ in$^2 = 10.51$ ksi

$Kl/r = (1.0)(50.91 \text{ in})(10.601 \text{ in}) = 84.71$

$Fa = 18.05$ ksi (AISC, 1973:5-87)

$f_b = M/S = 0.39$ k-in$/0.352$ in$^3 = 1.11$ ksi

$Fb = 0.6Fy = (0.6)(50) = 30.0$ ksi

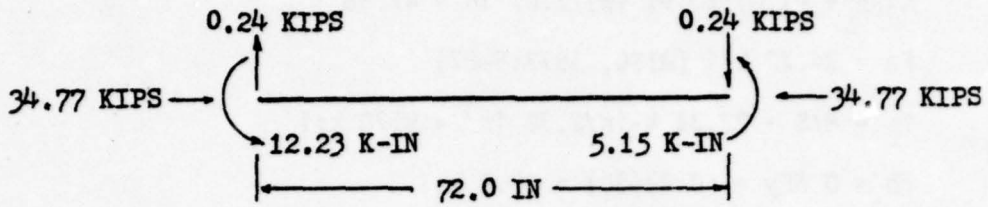
$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(84.71)^2 = 20.76$

1.6-1a $10.51/18.05 + 1.11/30.0(0.85/1 - 10.51/20.76) = 0.646 < 1.0$ O.K.

1.6-1b $10.51/30.0 + 1.11/30.0 = 0.387 < 1.0$ O.K.

The web members as presented met the combined stress requirements.

The bottom chord was a 3-1/2 X 3 X 3/8 in double angle with the 3 in legs together. Maximum forces are in members 5 and 37 as shown.



$A = 4.59\ in^2$, $IZ = 3.69\ in^4$, $S = 1.70\ in^3$, $r = 0.897$ in

$b/t_w = 3/0.375 = 8.0 < 10.75$ O.K. (no local buckling)

$f_a = P/A = 34.77\ kips/4.59\ in^2 = 8.23$ ksi

$Kl/r = (1.0)(72.0\ in)/0.897\ in = 80.27$

$Fa = 18.96$ ksi (AISC, 1973:5-87)

$f_b = M/S = 12.23\ k\text{-}in/1.70\ in^3 = 7.19$ ksi

$Fb = 0.6Fy = (0.6)(50) = 30.0$ ksi

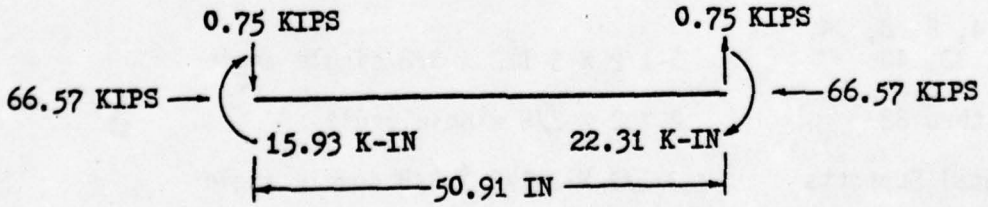
$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(80.27)^2 = 23.12$

1.6-1a $8.23/18.96 + 7.19/30.0(0.85/1 - 8.23/23.12) = 0.750 < 1.0$ O.K.

1.6-1b $8.23/30.0 + 7.19/30.0 = 0.514 < 1.0$ O.K.

All bottom chord members met the combined stress requirements.

The diagonal support was a 3-1/2 X 3-1/2 X 3/8 in double angle. Maximum forces were in members 1 and 41 as shown.



$A = 4.97\ in^2$, $IZ = 5.73\ in^4$, $S = 2.30\ in^3$, $r = 1.07$ in

$b/t_w = 3.50/0.375 = 9.33 < 10.75$ O.K. (no local buckling)

$f_a = P/A = 66.57\ kips/4.97\ in^2 = 13.39$ ksi

$Kl/r = (1.0)(50.91 \text{ in})/1.07 \text{ in} = 47.58$

$Fa = 24.72$ ksi (AISC, 1973:5-87)

$f_b = M/S = 22.31 \text{ k-in}/2.30 \text{ in}^3 = 9.70$ ksi

$Fb = 0.6Fy = (0.6)(50) = 30.0$ ksi

$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(47.58)^2 = 65.82$

1.6-1a $13.39/24.72 + 9.70/30.0(0.85/1 - 13.39/65.82) = 0.886 < 1.0$ O.K.

1.6-1b $13.39/30.0 + 9.70/30.0 = 0.770 < 1.0$ O.K.

The two diagonal supports met the combined stress requirements.

Summary of Secondary Frame. The secondary frame was analyzed using the two loading conditions. The members were sized to support the maximum combined stress. Table C-2-1 presents the secondary frame members.

TABLE C-2-1

SECONDARY FRAME MEMBERS

Top Chord	6 X 4 X 5/16 in double angle, 4 in legs together
Bottom Chord	3-1/2 X 3 X 3/8 in double angle, 3 in legs together
Web Members	
2, 4, 6, 8, 34, 36, 38, 40	3-1/2 X 3-1/2 X 3/8 single angle
10 thru 32	2 X 2 X 3/8 single angle
Diagonal Supports	3-1/2 X 3-1/2 X 3/8 double angle
Vertical	3-1/2 X 3-1/2 X 3/8 single angle

Main Frame. The major effort was expended on analysis of the 60 foot building system. This building provided the maximum force and moment

conditions required for the design of the frame, columns, and foundations. Once a satisfactory structure was established it would be the nucleus for developing the remaining seven frame configurations. Each building height required two configurations of the main frame. One system is horizontal across the top chord as shown in Figure C-2-3. The other system is shown in Figure C-2-4 and has a top chord dipping 1.75 degrees to provide roof drainage. Each of these two systems had to be analyzed for the four building heights. The two main frame configurations also had to be analyzed using interior columns and wind uplift forces. The frames were modeled as a four bay continuous frame. Each bay was 60 feet, therefore, the model was 240 feet long.

Considerable time was required to develop a realistic wind force model. This has been fully discussed in the main text. The analysis was started by applying the wind forces to the preliminary frame. The result was an over stress of the web members and top chord. An iterative process of STRESS analysis, member selection, and combined stess evaluation was used to develop the main frame. An important element was the relative stiffness of the columns. It should be noted that the main frame and columns were designed concurrently. Once the 60 foot building system met the established deflection and engineering requirements the frame members were analyzed with columns proposed for the various building heights.

The evaluations of the level frame, 60 foot building is presented as a representation of the calculations required to insure the members meet the AISC combined stress requirements.

The top chord was a 6 X 4 X 3/8 in double angle, 6 in legs together This member is present in the frame in two lengths. Adjacent to the

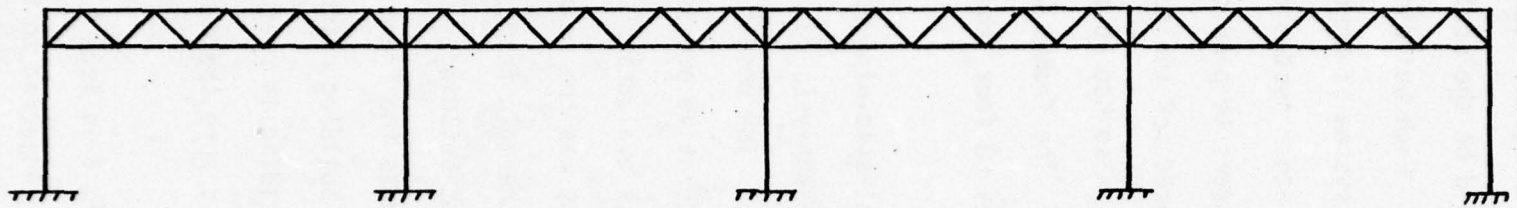


FIGURE C-2-3 LEVEL TOPPED FRAME

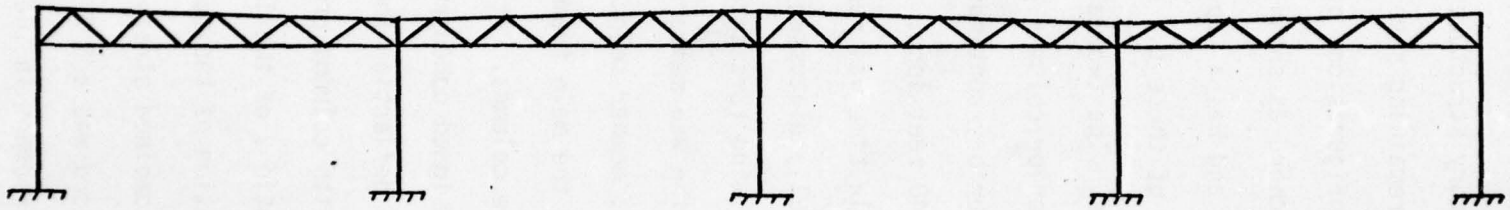
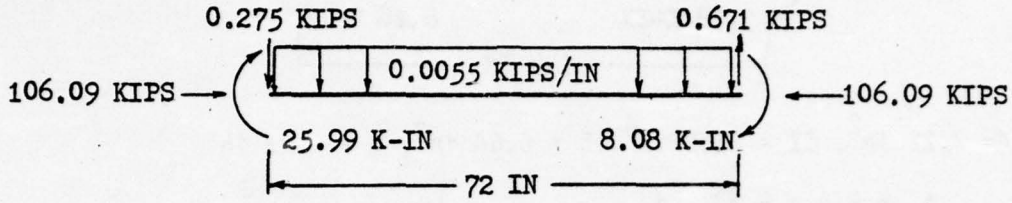


FIGURE C-2-4 SLOPED TOPPED FRAME

columns it is six feet long between joints. Throughout the remainder of the truss it is 12 feet long. Both lengths will be evaluated. The maximum forces in the six foot members were as shown.



$A = 7.22\ in^2$, $IZ = 26.9\ in^4$, $S = 6.64\ in^3$, $r = 1.93$ in

$b/t_w = 6/0.375 = 16 > 10.75$ (local buckling applies)

When $76/\sqrt{Fy} < b/t_w < 155/\sqrt{Fy} = 10.75 < 16 < 21.92$

$Qs = 1.340 - 0.00447(b/t_w)\sqrt{Fy}$

$Qs = 1.340 - 0.00447(16)7.07 = 0.834$

$Cm = 0.85$

$f_a = P/A = 106.09\ kips/7.22\ in^2 = 14.69$ ksi

$Kl/r = (1.0)(72.0\ in)/1.92\ in = 37.5$

$Fa = 26.18$ ksi (AISC, 1973:5-87)

$f_b = M/S = 25.99\ k\text{-}in/6.64\ in^3 = 3.91$ ksi

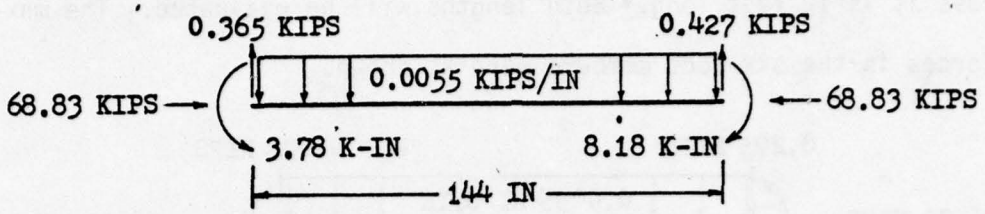
$Fb = Qs(0.6)Fy = (0.834)(0.6)(50) = 25.02$ ksi

$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(27.5)^2 = 107.06$ ski

1.6-1a $14.69/26.18 + 3.91/25.02(0.85/1 - 14.69/107.06) = 0.715 < 1.0$ O.K.

1.6-1b $14.69/30.0 + 3.91/25.02 = 0.646 < 1.0$ O.K.

The short top chord members met the combined stress requirements. The maximum forces in the 12 foot top chord were as shown.



A= 7.22 in^2, IZ = 26.9 in^4, S = 6.64 in^3, r = 1.93 in

f_a = P/A = 9.53 ksi

Kl/r = (1.0)(144.0 in)/1.93 in = 74.61

Fa = 20.07 ksi (AISC, 1973:5-87)

f_b = M/S = 8.18 k-in/6.64 in^3 = 1.23 ksi

Fb = 25.02 ksi

Fe' = 149,000/$(Kl/r)^2$ = 149,000/$(74.61)^2$ = 26.77 ksi

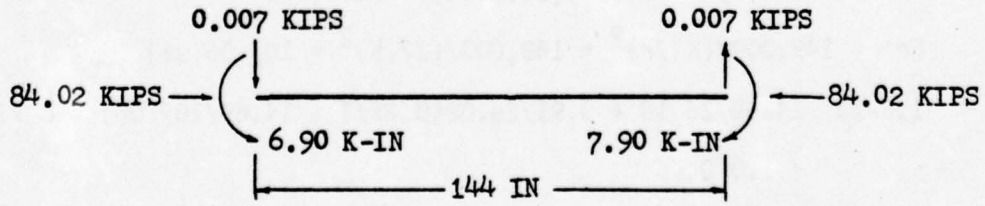
1.6-1a 9.53/20.07 + 1.23/25.02(0.85/1 - 9.53/26.77) = 0.539

< 1.0 O.K.

1.6-1b 9.53/30.0 + 1.23/25.02 = 0.367 < 1.0 O.K.

The long top chord members met the combined requirements.

The bottom chord was a 6 X 4 X 7/16 in double angle, 6 in legs together. The maximum forces in the bottom chord were as shown.



A = 8.37 in^2, IZ = 30.9 in^4, S = 7.66 in^3, r = 1.92 in

b/t_w = 13.71 > 10.75 (local buckling applies)

When $76/\sqrt{Fy} < b/t_w < 155/\sqrt{Fy}$ = 10.75 < 1.371 < 21.92

$Qs = 1.340 - 0.00447(b/t_w)\sqrt{Fy}$

$Qs = 1.340 - 0.00447(13.71)7.07 = 0.907$

$Cm = 0.85$

$f_a = P/A = 84.02 \text{ kips}/8.37 \text{ in}^2 = 10.04 \text{ ksi}$

$Kl/r = (1.0)(144.0 \text{ in})/1.92 \text{ in} = 75.0$

$Fa = 19.99 \text{ ksi}$ (AISC, 1973:5-87)

$f_b = M/S = 7.90 \text{ k-in}/7.66 \text{ in}^3 = 1.03 \text{ ksi}$

$Fb = Qs(0.6)Fy = (0.907)(0.6)(50) = 27.21 \text{ ksi}$

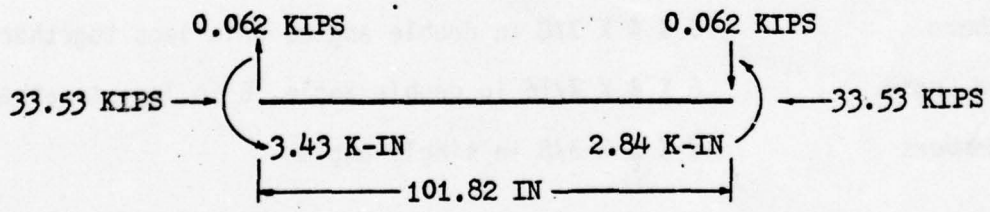
$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(75.0)^2 = 26.49 \text{ ksi}$

1.6-1a $10.04/19.99 + 1.03/27.21(0.85/1 - 10.04/26.49) = 0.554 < 1.0$ O.K.

1.6-1b $10.04/30.0 + 1.03/27.21 = 0.372 < 1.0$ O.K.

The bottom chord members met the combined stress requirements.

The web members were 5 X 3 X 3/8 in single angles. The maximum forces in the web members were shown.



$A = 2.86 \text{ in}^2$, $IZ = 7.37 \text{ in}^4$, $S = 2.24 \text{ in}^3$, $r = 1.61 \text{ in}$

$b/t_w = 5/0.375 = 13.33 > 10.75$ (local buckling applies)

When $76/\sqrt{Fy} < b/t_w < 255/\sqrt{Fy} = 10.75 < 13.33 < 21.92$

$Qs = 1.340 = 0.00447/(b/t_w)\sqrt{Fy}$

$Qs = 1.340 - 0.00447(13.33)7.07 = 0.919$

$Cm = 0.85$

$f_a = P/A = 33.53 \text{ kips}/2.86 \text{ in}^2 = 11.72 \text{ ksi}$

$Kl/r = (1.0)(101.82 \text{ in})/1.61 \text{ in} = 63.24$

$Fa = 22.16$ ksi (AISC, 1973:5-87)

$f_b = M/S = 3.43$ k-in/2.24 $in^3 = 1.53$ ksi

$Fb = Qs(0.6)Fy = (0.919)(0.6)(50) = 27.57$ ksi

$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(63.24)^2 = 37.26$ ksi

1.6-1a $11.72/22.16 + 1.53/27.57(0.85/1 - 11.72/37.26) = 0.598 < 1.0$ O.K.

1.6-1b $11.72/30.0 + 1.53/27.57 = 0.446 < 1.0$ O.K.

The web members met the combined stress requirements.

Summary of Main Frame. The main frame was modeled and evaluated with both a horizontal and sloped top chord. The selected frame members are presented in Table C-2-2.

TABLE C-2-2

MAIN FRAME MEMBERS

Top Chord	6 X 4 X 3/8 in double angle, 6 in legs together
Bottom Chord	6 X 4 X 7/16 in double angle, 6 in legs together
Web Members	5 X 3 X 3/8 in single angle

Column Design. All of the columns were evaluated using loading conditions 1 and 2. The controlling factor in the exterior column design was the allowable sidesway (deflection). The amount of horizontal movement was limited to 1/200 of the column's length. The sidesway was measured on the leeward end of the four bay model. Expansion joints would be located at approximately these points in the structural system. Table C-2-3 is a summary of the exterior column deflections.

TABLE C-2-3

EXTERIOR COLUMN DEFLECTION

BUILDING HEIGHT (FT)	COLUMN (SIZE)	DEFLECTION (IN)	RATIO (Δ/1)
30	W14X84	1.642	1/219
40	W21X127	2.017	1/238
50	W27X145	2.541	1/236
60	W33X152	3.308	1/218

The interior columns were analyzed using both loading conditions. Loading 1 was the controlling condition. The force distribution for the four bay model was symmetrical about the center columns as shown in Figure C-2-5.

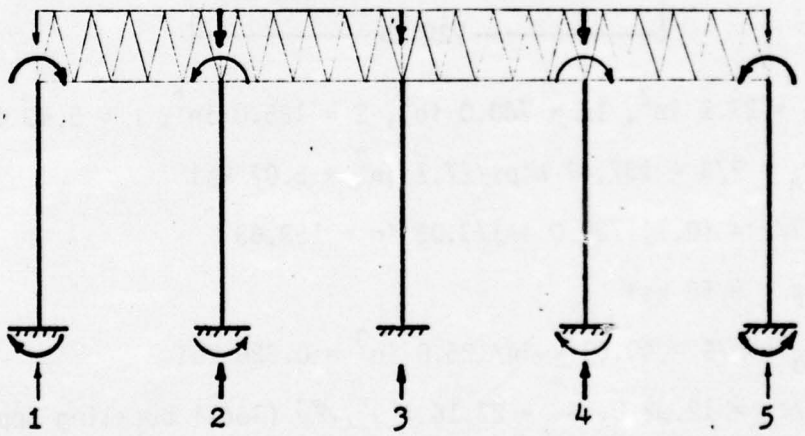


FIGURE C-2-5 INTERIOR COLUMN MODEL

Column 3 has only an axial load applied to it due to symmetry. Columns 2 and 4 have the maximum axial load and a small moment. Columns 1 and 5 have the maximum moment but a relatively small axial load.

The column's unsupported length was of major concern during the analysis. The selection of a value of K was discussed in the main text. The 60 foot high column system is presented as an example of the interior column evaluation. All columns were checked and complied with the weak axis bending stress requirements.

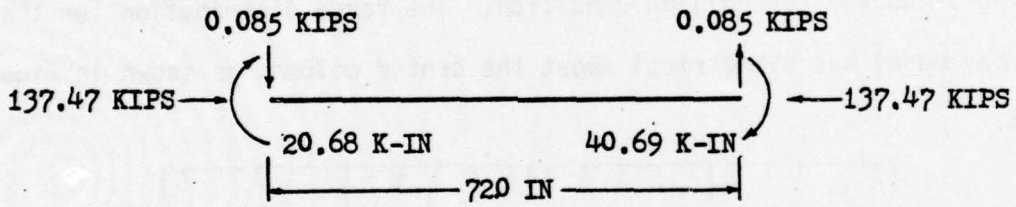
$f_a = P/A = 130.47 \text{ kips}/27.1 \text{ in}^2 = 5.07 \text{ ksi}$

$Kl/r = (0.7)(720.0 \text{ in})/3.08 \text{ in} = 163.6$

$Fa = 5.58 \text{ ksi}$ (AISC, 1973:5-84)

5.07 ksi (actual) < 5.58 ksi (allowable) O.K.

An example of the combined stress evaluation is as follows:



$A = 27.1 \text{ in}^2$, $IZ = 789.0 \text{ in}^4$, $S = 125.0 \text{ in}^3$, $r = 5.40 \text{ in}$

$f_a = P/A = 137.47 \text{ kips}/27.1 \text{ in}^2 = 5.07 \text{ ksi}$

$Kl/r = (0.7)(720.0 \text{ in})/3.08 \text{ in} = 163.63$

$Fa = 5.58 \text{ ksi}$

$f_b = M/S = 40.69 \text{ k-in}/125.0 \text{ in}^3 = 0.326 \text{ ksi}$

$b/t_w = 12.62/0.545 = 23.16 > 95/\sqrt{Fy}$ (local buckling applies)

When $95/\sqrt{Fy} < b/t_w < 173/\sqrt{Fy}$ (AISC, 1973:5-115)

$15.83 < 23.16 < 28.83$

$Qs = 1.415 - 0.00437(b/t_w)\sqrt{Fy}$

$Qs = 1.415 - 0.00437(23.16)(6.0) = 0.807$

$Fb = Qs(0.6)Fy = (0.807)(0.6)(36.0) = 17.43 \text{ ksi}$

$Fe' = 149{,}000/(Kl/r)^2 = 149{,}000/(163.63)^2 = 5.57 \text{ ksi}$

$$Cm = 0.6 - 0.4M_1/M_2 \geq 0.4$$

$$Cm = 0.6 - (0.4)(20.68)/40.69 = 0.40$$

1.6-1a $5.07/5.58 + 0.326/17.43(0.40/1 - 5.07/5.57) = 0.99 < 1.0$ O.K.

1.6-1b $5.07/22.0 + 0.326/17.43 = 0.249 < 1.0$ O.K.

The forces on columns 1 and 5 were also evaluated using the combined stress requirements. Even with the large moment the members met the requirements. A summary of interior columns is presented in Table C-2-4.

TABLE C-2-4

INTERIOR COLUMNS

Height	30 ft	40 ft	50 ft	60 ft
Size	W12X53	W10X60	W14X78	W12X92

Box columns were used in the corners of the structure due to wind loading from two directions. The columns within the corner had to be equally stiff about both axes to comply with the deflection criteria. Deflection is a function of the member's moment of inertia. From the exterior column design the moment of inertia about the strong axis was available. The design required that a member be selected that would have the same moment of inertia about both its axes. For construction economy a square column assembled from standard plate was designed as illustrated. The strong axis moment of inertia of the W33X152 exterior column was 8160 inches^4.

$$Iyy = Ixx = (2)Ad^2 + (2)(1/12)bh^3 + (2)(1/12)b_1h_1^3$$

$$Iyy = (2)(25.0\text{ in})(0.75\text{ in})(12.5\text{ in})^2 + (0.617)(25\text{ in})(0.75\text{ in})^3 + (0.167)(24.25\text{ in})^3(0.75\text{ in}) = 7643.0\text{ in}^4$$

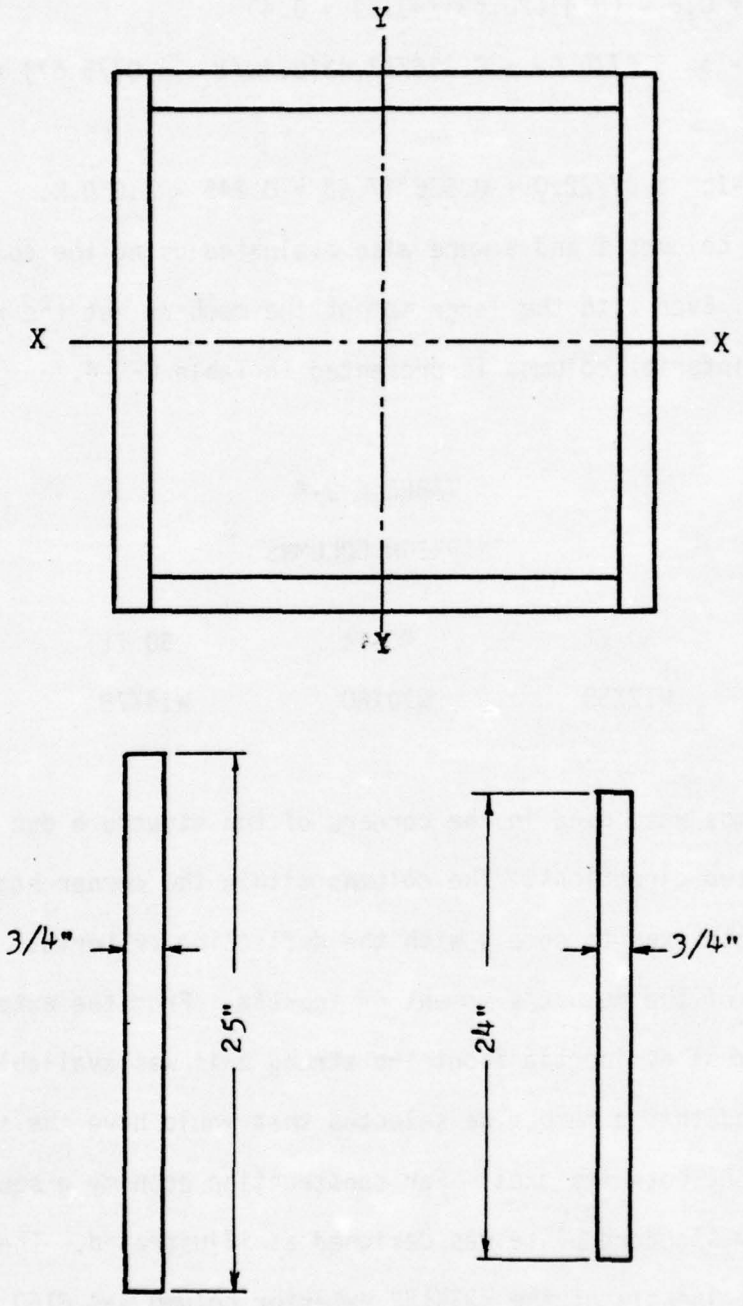


FIGURE C-2-6 BOX COLUMN

$A = (2)(25.0\ in)(0.75\ in) + (2)(24.25\ in)(0.75\ in) = 73.88\ in^2$

$r = \sqrt{Iyy/A} = \sqrt{7643.0\ in^4/73.88\ in^2} = 10.17\ in$

$S = 2Iyy/d = (2)(7643.0\ in^4)/(25.0\ in) = 611.44\ in^3$

The box columns were evaluated for combined stress and met the AISC requirements. Deflection was the controlling factor for the box columns. Table C-2-5 is a summary of the acceptable box column deflection relative to the four building heights.

TABLE C-2-5

BOX COLUMN DEFLECTION

BUILDING HEIGHT (FT)	COLUMN (SIZE)	DEFLECTION (IN)	RATIO (ΔL)
30	12X12X11/16	1.53	1/235
40	20X20X5/8	1.88	1/255
50	22X22X3/4	2.64	1/227
60	25X25X3/4	2.98	1/241

Earthquake Force Calculations. To determine the lateral force that acts on the exterior structure, wind and earthquake forces were considered to arrive at the controlling situation for design. The design wind force on the side of the warehouse, 42.9 pounds per square foot, is equivalent to a total force of 3.73×10^6 pounds on a 1320 foot by 60 foot exterior wall. The equation to calculate the resultant earthquake shear force is (Gaylord, 1968:3-23):

$$V = ZKCW \qquad (C\text{-}2\text{-}1)$$

where:

Z = 0.25 for seismic zone 1 (Amrhein, 1973:26)

K = 0.67 for buildings with a ductile moment resisting space frame designed to resist the entire lateral force (Gaylord, 1968:3-24)

C = 0.05/T (Gaylord, 1968:3-23)

$T = 0.05\ h_n/\sqrt{D}$ (Gaylord, 1968:3-23)

h_n = Height above base uppermost level in main portion of structure, ft

D = Dimension of building parallel to applied forces, ft

W = Weight of structure, 39.8×10^6 lbs

The resulting earthquake shear force is 0.449×10^6 lbs utilizing Equation (C-2-1). Since this force is less than the design wind force of 3.73×10^6 lbs the wind force governs.

Cost Summary. The estimated unit prices were developed using Means 1976 Building Construction Cost Data for Washington, D.C. Steel prices have been factored to include fabrication, transportation, erection, painting, and addition for long lengths. The estimated quantity and cost of each system is presented in the following tables.

TABLE C-2-6

COLUMN AND FRAME QUANTITY

NOT INCLUDING FIRE WALLS

	COLUMNS			
	EXTERIOR (EA)	INTERIOR (EA)	BOX (EA)	STUB (EA)
Operating Area	162	50	60	70

TABLE C-2-6 CONTINUED

COLUMN AND FRAME QUANTITY

NOT INCLUDING FIRE WALLS

	COLUMNS			
	EXTERIOR (EA)	INTERIOR (EA)	BOX (EA)	STUB (EA)
Train Sheds	34	0	0	0
General Storage Area	195	169	50	110
Mechanized Area	85	26	50	66

	FRAMING		
	MAIN (LF)	SECONDARY (LF)	JOISTS (EA)
Operating Area	9,660	25,800	4,300
Train Sheds	960	0	162
General Storage Area	27,750	39,720	7,260
Mechanized Area	11,190	12,000	2,420

TABLE C-2-7

COLUMNS Fy 36 STEEL (TONS)

	EXTERIOR	INTERIOR	BOX	STUB	TOTAL
Operating Area	244.9	42.9	114.3	25.2	427.3
Train Sheds	51.4	0	0	11.5	62.9
General Storage Area					
30 ft bldg	294.8	161.2	90.0	39.6	585.6
40 ft bldg	569.6	2,333.2	176.6	91.8	1,071.2
50 ft bldg	791.7	368.1	283.4	154.0	1,598.2
60 ft bldg	978.1	513.1	380.3	246.8	2,118.3
Mechanized Area					
30 ft bldg	128.5	24.8	90.0	23.8	267.1
40 ft bldg	248.3	35.9	176.6	54.7	515.5
50 ft bldg	345.1	56.8	283.4	92.4	777.7
60 ft bldg	426.4	78.9	380.3	148.1	1,033.7

The quantity of high strength Fy steel in the framing joists and bracing is as follows:

General Storage Area

Main frame (27,750 lf)(67.06 plf) = 930.5 tons

Secondary frame (39,720 lf)(50.0 plf) = 993.0 tons

18 H 5 joist (7260 ea)(240 lb/ea) = 871.2 tons

Bracing (7260 ea)(28 lb/ea) = 101.6 tons

Mechanized Area

Main frame (11.190 lf)(67.06 plf) = 375.2 tons

Secondary frame (12,000 lf)(50.0 plf) = 300.0 tons

18 H 5 joists (2420 ea)(240 lb/ea) = 290.4 tons

Bracing (2420 ea)(28 lb/ea) = 33.9 tons

Operating Area

Main frame (9660 lf)(67.06 plf) = 323.9 tons

Secondary frame (25,800 lf)(50.0 plf) = 645.0 tons

12 H 3 joists (4300 ea)(93.6 lb/ea) = 201.2 tons

Bracing (4300 ea)(16.8 lb/ea) = 36.1 tons

Train Sheds

Main frame (9660 lf)(67.0 plf) = 32.2 tons

40 LH 09 Joists (162 ea)(690 lb/ea) = 55.9 tons

Bracing (162 ea)(76.4 lb/ea) = 6.2 tons

The estimated price for A 36, Fy 36 steel, was $880/T for lengths up to 40 feet. The estimate increased from $883/T to $885/T for lengths between 40 and 60 feet. The estimated cost for all high strength Fy 50 steel was $920/T. The estimated cost for the steel structure is presented as follows:

Operating Area (427.3T)($880/T) + (1206.2T)($920/T) = $1,485,728

Train Sheds (62.9T)($880/T) + (94.3T)($920/T) = $ 142,108

General Storage Area

30 ft bldg (585.6T)($880/T) + (2896.3T)($920/T) = $3,179,924

40 ft bldg (1071.2T)($883/T) + (2896.3T)($920/T) = $3,610,466

50 ft bldg (1598.2T)($884/T) + (2896.3T)($920/T) = $4,077,405

60 ft bldg (2118.3T)($885/T) + (2896.3T)($920/T) = $4,539,292

Mechanized Area

30 ft bldg (267.1T)($880/T) + (999.5T)($920/T) = $1,154,588

40 ft bldg (515.5T)($883/T) + (999.5T)($920/T) = $1,374,727

50 ft bldg (777.7T)($884/T) + (999.5T)($920/T) = $1,607,027

60 ft bldg (1033.7T)($885/T) + (999.5T)($920/T) = $1,834,365

The volume of the four major sections in units of 1000 cubic feet is presented in Table C-2-8.

TABLE C-2-8

VOLUME OF MAJOR SECTIONS

	BUILDING HEIGHT (FT)			
	30	40	50	60
Operating Area (464,400 sq ft)	13,932	------	------	------
Train Sheds (76,800 sq ft)	2,304	------	------	------
General Storage Area (1,306,800 sq ft)	39,204	52,272	65,340	78,405
Mechanized Area (435,600 sq ft)	13,068	17,424	21,780	26,136

The final cost estimate for the structural system in units of $/1000 cubic feet is presented in Table C-2-9.

TABLE C-2-9

ESTIMATED COST OF STEEL STRUCTURAL SYSTEM

($/1000 CU FT)

	BUILDING HEIGHT (FT)			
	30	40	50	60
Operating Area	106.64	-----	-----	-----
Train Sheds	61.67	-----	-----	-----
General Storage Area	81.11	69.07	62.40	57.90
Mechanized Area	88.35	78.90	73.78	70.19

APPENDIX C-3

Interior Wall Appendix Symbols

As - Area of tensile reinforcement

b - Width of compression face of wall section

Cp - Horizontal force factor used in computing seismic forces

d - Distance from compression face to centroid of tensile reinforcement

DL - Dead load

e - Eccentricity

Em - Modulus of elasticity of masonry in compression, 1000 fm'

Es - Modulus of elasticity of steel

f_a - Computed axial stress

f_b - Computed flexural stress

f_c' - Ultimate compressive strength of concrete

f_m - Allowable compressive masonry stress in flexure

f_m' - Ultimate compressive strength of masonry

f_s - Stress in tensile reinforcement

ft - Feet

ft-lbs - Foot pounds, moment

Fa - Permitted axial stress at the point under consideration

Fb - Flexural stress permitted for bending load

h - Clear height of wall

h' - Effective height of wall

in - Inches

j - Ratio of distance between resultants of compressive tensile

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stress to effective depth

k - Ratio of distance between extreme compression fiber and neutral axis to depth

lb - Pound

M - External moment

n - Es/Em

p - As/bd

pcf - Pounds per cubic foot

plf - Pounds per linear foot

psf - Pounds per square foot

psi - Pounds per square inch

P - Axial load

sq in - Square inches

sq ft - Square feet

t - Thickness of wall

t' - Effective thickness of wall

UBC - Uniform Building Code

w - Uniformly distributed load

Wp - Weight of wall in psf

Z - Numerical coefficient used in computing seismic force

APPENDIX C-3

INTERIOR WALLS

Seismic forces on the interior walls were computed using the equation:

$$Fp = ZCpWp \text{ (Amrhein, 1973:27)} \qquad \text{(C-3-1)}$$

The assumed location was in seismic zone one. The value of Z was 0.25 for the zone. Cp of 0.2 was used for internal nonbearing walls and 1.0 for cantilever parapets and cantilever walls (Amrhein, 1973:20). The force varied from 5.8 to 7.35 pounds per square foot for that portion of the wall between floor and roof line. A seismic force of 29 to 36.75 pounds per square foot was computed for the parapet to the wall. These seismic forces were less than the forces used in the design. Ten pounds per square foot was the recommended design force for the interior walls (AFM 88-3, 1973:4-2). The computed exterior lateral wind force was 42.9 pounds per square foot.

The dead load of the wall, 10 pounds per square foot, varied for each building height. An attempt was made to keep the nominal thickness of the wall at a minimum. Concrete masonry blocks were selected as a material to use in the construction of the wall. The selected wall cross section for the 39 and 49 foot walls was a single wythe concrete masonry block with reinforcing in the cores, and with the cores fully grouted. The selected cross section for the two higher walls was a double wythe concrete masonry wall with a four inch space between the wythes. The cores in the concrete blocks were left unfilled. Reinforcing was placed in the four inch space and the space was filled with grout. The wall had to be capable of resisting a lateral force from either side. The reinforcing

steel reacted in tension only, and was placed in the center of the wall for the most effective and economical placement (Amrhein, 1973:82).

The wall bearing area supported the wall dead load. The thickness of the bearing area was the nominal wall thickness for the single wythe wall. Effective thickness was required in computing the bearing area of the double wythe wall. The effective thickness for the double wythe wall was twice the effective thickness for a single concrete block plus the four inches of grout.

The Uniform Building Code (UBC) has a requirement that the height over thickness ratio cannot exceed 48 for a nonbearing, reinforced, interior wall. The UBC allows use of effective height in computing this ratio (Amrhein, 1973:67). The height of the parapet was assumed to be three feet. Lateral support for the parapet section of the wall was only at the roof line of the building. The parapet was modeled as a cantilever section. The effective height for the cantilever wall was twice the height of the wall (AFM 88-3, 1973:4-7). The section of the wall between floor and roof was assumed to be fixed at the floor and pinned by the frame system at the roof. The fixed base of the wall resulted in an inflection point in its vertical span when the lateral force was applied. The height of the wall from its base to the inflection point was 0.2 times the distance between the floor and the roof line. The roof line was assumed to be a horizontal plane for the interior wall calculations. That portion of the wall above the inflection point was assumed to be a simple span pinned at each end for moment calculations. The lower wall section and parapet were assumed to be a cantilever section for moment calculations. The wall was assumed to have a uniform cross section. No tension was to

be carried by the masonry. A one foot long section of the wall was used in the design process. The wall design procedure was the same for each of the four heights. The 49 foot high wall is used to illustrate the design procedure.

The equations were taken from Amrhein's Reinforced Masonry Engineering Handbook.

Wall Design. The required total height to consider was 49 feet. The height between supports of the floor and roof line was 46 feet. See Figure C-3-1 for illustration.

$h' = 0.8 \times 46 = 36.8$, use 37 ft

$t_{min} = h'/48 = 37 \times 12/48 = 9.25$ in

A thickness of 10 inches was tried.

Fully grouted concrete masonry block dimensions were assumed and therefore, 1500 psi was allowed as the ultimate compressive strength of the masonry block (Amrhein, 1973:19). The reinforcement was placed into the cores. Type S mortar and 2000 psi grout were selected and ASTM A615 - Grade 40 steel with a f_s of 20,000 psi was specified. Joint reinforcing material was 3/16 inch diameter wire (Amrhein, 1973:22).

$M = wl^2/8 = 1/8 \times 10 \times 37 \times 37 = 1711$ ft-lbs

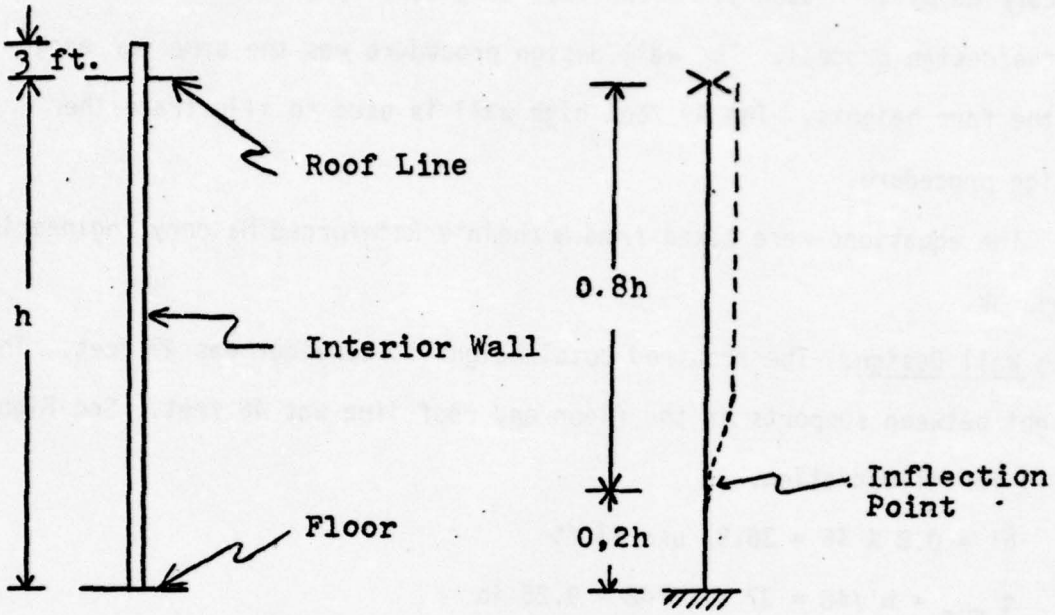
$Fb = f_m = 1/3\ f_m' = 500$ psi

By using one half stresses for Fa and Fb, there was no requirement for a special concrete inspector to be on the site during wall construction (Amrhein, 1973:18).

$Fb = 250$ psi

$K = M/(bd^2) = 1711 \times 12/(12 \times 5 \times 5) = 68.44$ psi

$K = 1/2\ kjf_m$



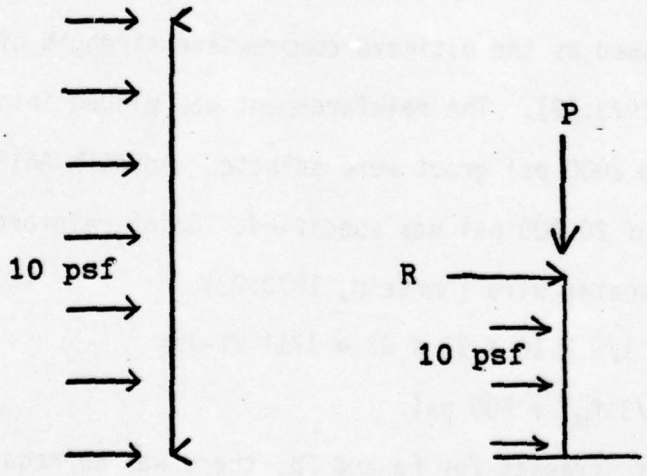


FIGURE C-3-1 WALL MODEL

$k = 1/(1 + f_s/nf_m) = 1/(1 + 20{,}000/(40 \times 250)) = .3333$

$j = 1 - k/3 = .8889$

K balanced = 1/2 X .3333 X .8889 X 250 = 37.03 psi

If K was greater than K balanced, then the wall required compression steel, or overreinforcing, or a thicker cross section (Amrhein, 1973:98). Compression steel was eliminated due to the reason for placing the tension steel in the center of the wall.

Full stresses were tried and Fb was equal to 500 psi.

K balanced = 74.07 psi for full stresses

$p = K/(f_s j) = 68.44/(26{,}700 \times .8889) = .0029$

Two values were used in computing the required steel area. The tensile stress of the reinforcing steel, f_s, and the maximum combined flexural stress, f_b. The value of f_b was determined using the relationship, $f_a/Fa + f_b/Fb \leq 1.33$. The UBC allows use of a 1/3 overstress when computing stress resulting from temporary short term loading resulting from wind. The same 1/3 overstress was applied to f_s for the steel reinforcement (Amrhein, 1973:64). The larger calculated steel area was used. Tensile stress, f_s, was used to compute the ratio, p, for pure bending stresses. Flexural stress, f_b, was used to compute the ratio, p, for combined bending and axial stresses. The steel was assumed to act in tension, and compression was only on part of the wall.

For vertical bending stresses:

As = pbd = .0029 X 12 X 5 = .174 in^2 per foot of wall

Maximum moment for this section of the wall was at the mid point.

DL mid point = 3 X 116 + 1/2 X 37 X 116 = 2494 lb

$Fa = .2f_m'(1 - (h/48t)^3) = .2 \times 1500 \times (1 - (37 \times 12/(48 \times 10))^3)$

$= 62.6$ psi

Note: The 48 used in the denominator was allowed by UBC Table I-24, since calculations were for interior, nonbearing, reinforced walls. Full stress was used for Fa since the full stress for Fb was used.

$f_a = P/A = 2494/(12 \times 10) = 20.8$ psi

f_b max $= (1.33 - f_a/Fa)Fb = (1.33 - 20.6/62.6)(500) = 498.8$

$K = 1/2\ kjf_m$

$kj = 68.44 \times 2/498.8 = 0.274$

$k(1 - k/3) = 0.274$

$k = 0.306$

$j = 0.898$

$0.306 = 1/(1 + f_s/(20 \times 498.8))$

$f_s = 22{,}625$ psi

$p = 68.44/(22{,}625 \times .898) = .0034$

For masonry stresses, As = 0.204 square inches per foot of wall. Try number 8 reinforcing bars at 46 inch spacing.

$0.79/46 \times 12 = 0.206$ sq in per foot

Since this series of calculations required special inspection of the concrete, a 12 inch wall thickness was tried.

For vertical bending stresses, As = $.002 \times 12 \times 6 = .144$ in^2

For combined bending stresses, As = $.0036 \times 12 \times 6 = .259$ in^2

A wall with thickness of 12 inches requires number 9 bars spaced every 46 inches.

The lower wall section was modeled as a nine foot high cantilever section. The reaction from the lower end of the upper interior section

was transferred to the top of this section. See Figure C-3-1 for illustration. The following calculations are for a wall thickness of ten inches.

Upper reaction, $R = wl/2 = 10 \times 37 \times 1/2 = 185$ plf

Upper wall and parapet weight, $P = 40 \times 116 = 4640$ plf

$h'/t = 2 \times 9 \times 12/10 = 21.6$

$Fa = 136.3$ psi

DL total $= 49 \times 116 = 5684$ plf

$f_a = 47.4$ psi

Moments were summed at the bottom of the wall.

$M = Rh + (1/2)wh^2 = 185 \times 9 + (10 \times 9 \times 9 \times 1/2) = 2070$ ft-lbs

$K = 82.8$ psi

K balanced = 37.03 psi

It was noted that the value of K was large compared with the value of K balanced. Try using full stresses.

$Fa = 272.6$ psi

f_b max = 578 psi

K balanced = 74.07 psi for full stress

The calculated value of K for the ten inch thick lower wall was greater than the value of K balanced for both one-half and full allowable stresses. The selected wall thickness for the entire wall was 12 inches since the wall was assumed to be a uniform cross section. Remaining calculations are for a 12 inch thick wall. Number 9 bars spaced every 46 inches was the required reinforcement for the upper wall section.

For the lower wall section:

$As = .0025 \times 12 \times 6 = .18$ in^2 for bending stresses

As = .0015 X 12 X 6 = .108 in^2 for combined bending stresses

This area of steel reinforcement was less than the area of steel in the upper wall section. The conservative approach was less than the area of steel in the upper wall section. The conservative approach was used and upper wall steel was extended into the lower section. Special concrete inspection was used in the lower section. The special inspection was carried three feet up into the upper section. The additional three feet was to insure full bond for the reinforcement in the lower section.

The parapet was also modeled as a cantilever section.

$M = 1/2wh^2 = 1/2 \times 42.9 \times 3 \times 3 = 193$ ft-lbs per foot

Moment capacity of upper wall steel was calculated.

$M = Asf_sjd = .256 \times 26{,}700 \times .8889 \times 6/12 = 3038$ ft-lbs per foot

Upper wall steel was extended into the parapet.

The UBC has a requirement that the total minimum steel in a reinforced wall must be no less than 0.002bt. It further states that the minimum reinforcement in one direction is .0007bt (Amrhein, 1973:26).

As = .0007 X 12 X 12 = .1008

The length of the wall between vertical columns is 60 feet. The wall was assumed to be continuous and an inflection point occurred at a point 0.2 X 60 feet from each support. Effective length of the wall was equal to $wl^2/11$ (Amrhein, 1973:68).

$M = wl^2/11 = 10 \times 36 \times 36/11 = 1178$ ft-lbs

K = 32.7 psi

For steel stress, p = .0014

For masonry stress, p = .0008

As = .0014 X 12 X 6 = .1008 in^2 per foot

As = .1008 X 49 = 4.9392 in^2 of horizontal reinforcing

Minimum steel, as directed by the UBC, was used in the horizontal direction.

The joint reinforcing wire was placed at 24 inch spacing.

49 X (12/24) - 1 = 24 rows of wire

24 X .0552 = 1.3248 in^2 of joint reinforcing wire

4.9392 - 1.3248 = 3.6144 sq in of horizontal steel remaining to be selected

At 48 inches spacing of reinforcement, 12.25 rows are required. Try number 5 bars.

12 X .31 = 3.72

13 X .31 = 4.03

Number 5 reinforcing bars were placed every 48 inches except 2 bars were placed at the roof line. Thirteen bars were used.

The footing was designed to obtain the maximum bearing pressure on the soil below 1000 psi. See Figure C-3-2 for illustration.

Wall weight = 49 X 140 = 6860 lb

Assumed footing size was 12 feet wide by two feet thick.

Footing weight = 12 X 2 X 150 = 3600 plf

Total load on soil = 10,460 plf

Moments were summed about bottom center of footing to get bearing pressure at toe of footing.

M = 185 X (9 + 2) + 1/2 X 9 X9 X 10 = 2530 ft-lbs

e = M/P = .242 ft

Middle third = 12/6 = 2

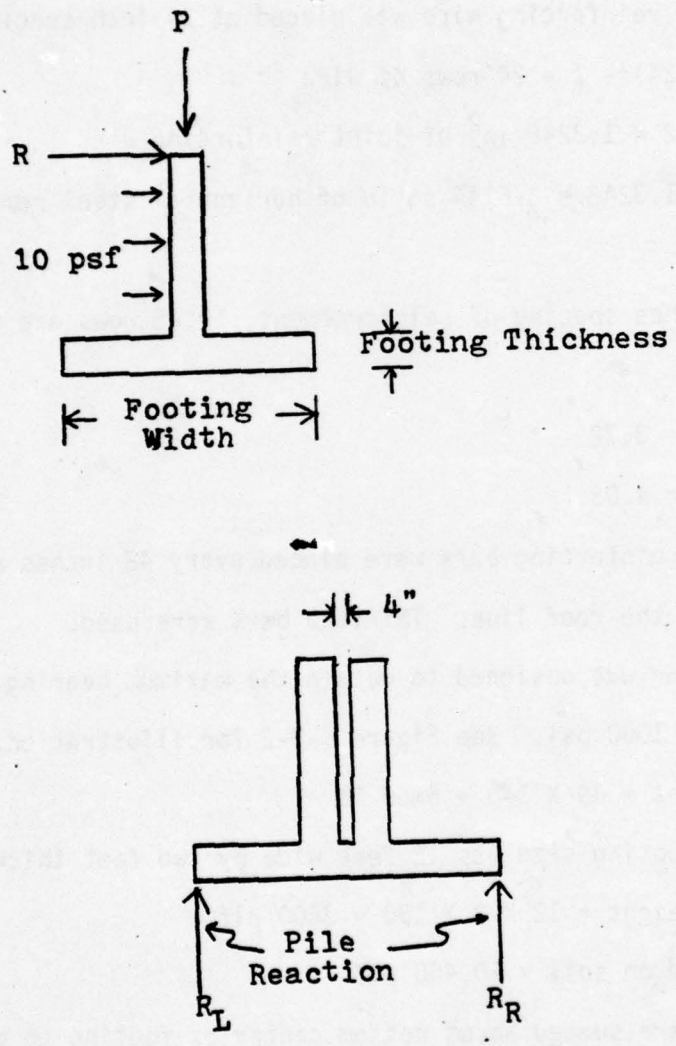


FIGURE C-3-2 FOOTING MODEL

Maximum force on soil = $(P/A)(1 + 6e/d) = (10,460/12)(1 + 6 \times .242/12)$

$= 977$ psi

For the double wall design, two of the 49 foot wall sections with a four inch cavity between wall sections were used. See Figure C-3-2.

Total wall weight was 13,720 plf.

Pile capacity was assumed to be 100 tons for a length of 50 feet.

Assumed footing size was 6 feet wide by 2 feet thick.

Footing weight = 6 X 2 X 150 = 1800 plf

Total dead load = 15,520 plf

$\Sigma M = 3 \times 15,520 + 2530 - 6R_L = 0$

$R_L = 8182$ lbs

One pile under each side of the footing was placed every 12 feet along the footing.

Table C-3-1 in the appendix has the interior wall specifications. Table C-3-2 lists the footing size or pile requirements for the single walls. Table C-3-3 lists the same information for the double walls. Piles were placed in pairs. One pile was needed to resist the overturning moment from each direction. Tables C-3-2 and C-3-3 indicate running spacing between pairs of piles along the wall. Table C-3-4 lists costs for the walls per 100 linear feet, total wall costs, and costs per 1000 cubic feet of storage space.

The fire protection requirements directed that the storage areas be divided into areas with a maximum of 80,000 square feet between fire walls. The interior walls were designed for 79,200 square feet between fire walls. The mechanized area measured 330 feet by 1,320 feet. This area has walls 1,320 feet long to separate it from the other areas. Five walls, each

330 feet long, were placed between the longer walls. The mechanized area was divided into five areas measuring 240 feet by 330 feet and one area that measured 120 feet by 330 feet. The general storage area was divided into 15 areas measuring 240 feet by 330 feet and three areas that measured 120 feet by 330 feet. These areas were selected to get the length of wall required to comply with the fire protection requirements.

The two walls that separate the mechanized area from the other two areas are included in the wall costs. The additional structural steel for these two walls and the costs for this steel was included in the column and frame analysis in this report. The remaining walls were designed strictly for fire protection. Additional structural steel costs are included for these walls.

TABLE C-3-1

INTERIOR WALL SPECIFICATIONS

Wall Height (Ft)	39	49	59	69
Wall Thickness (In)	10	12	16	20
Vertical Reinforcement Bar Size	7	9	9	10
Vertical Reinforcement Spacing (In)	46	46	48	48
Horizontal Reinforcement Bar Size	5	5	5	5
Horizontal Reinforcement Spacing (In)	48	48	32	24
No. Of Horizontal Joint Reinforcements At 24 In Spacing	19	24	29	34
Concrete Special Inspection Requirements Vertically From Bottom (Ft)	10	12	14	16

TABLE C-3-2

SINGLE WALL FOUNDATION REQUIREMENTS

Wall Height (Ft)	39	49	59	69
Footing Size (Ft)	8 X 1.5	12 X 2	14 X 2	--
Pile Spacing (Ft)	--	--	--	14

TABLE C-3-3

DOUBLE WALL FOUNDATION REQUIREMENTS

Wall Height (Ft)	39	49	59	69
Footing Size (Ft)	15 X 2	--	--	--
Pile Spacing (Ft)	--	12	10	8

TABLE C-3-4

INTERIOR WALL COSTS

Wall Height (Ft)	39	49	59	69
Single Wall ($/100 Linear Feet)	18,245	28,202	36,112	43,612
Additional Structural Steel ($/100 Linear Feet)	3,923	5,051	6,438	7,933
Double Wall ($/100 Linear Feet)	38,090	50,555	69,489	83,223
Interior Walls ($)	3,419,000	4,836,000	6,377,000	7,692,000
Interior Walls ($/1000 Cubic Feet)	49.91	56.28	61.70	63.69

APPENDIX C-4

Roofing Appendix Symbols

g - Gauge

R - Resistivity of material to heat transfer

U - Heat transfer coefficient, $U = 1/R$

APPENDIX C-4

ROOFING

Roof decks are constructed of many materials including poured in place concrete, precast concrete plank, precast gypsum, poured gypsum, and metal. Small differences in total roof weight in pounds per square foot amount to large amounts when applied to 50 acres of roof surface. A reduction in the total weight being supported resulted in a corresponding reduction in weight of frame members and columns. This combined to reduce foundation requirements.

Lightweight concrete was considered but eliminated. It is difficult to remove all the moisture during the curing process. The moisture becomes entrapped and results in blisters in the roof membrane when it is later released. Lightweight concrete does have some insulating qualities but it was eliminated because of the moisture. Gypsum roof planks had the best deck material insulating qualities. Moisture was not controlled in the 30 acres of general storage, and the high humidity in this area can cause deterioration of the deck. Concrete plank was not affected by the moisture, but weights and costs were higher than a steel deck.

Steel decking had no insulating qualities. Insulation was added to the steel deck and the resultant cost and weight were less than concrete plank or gypsum plank, and the steel with insulation had a higher "R" value. Table C-4-1 illustrates the comparisons. The designed purlin spacing was six feet. The selected roofing dead load of 10.2 pounds per square foot (Table C-4-5) and snow load of 20 pounds per square foot combined to yield a total load of 30.2 pounds per square foot. A 20 gauge

steel deck very easily supported this load with a six foot purlin spacing (Granco, 1971:3).

Open web steel framing was selected for the roof support. There was no suspended or false ceiling. The underside of the steel deck was left exposed. The insulation was not placed on the underside of the deck due to the high humidity in the general storage area. Nonrigid insulation will not provide a proper surface for applying a built-up roof. There are many rigid insulations available which do provide a smooth rigid surface for the membrane covering. Urethane and foam insulations are lighter in weight and higher in "R" value than other rigid insulations if the thickness of the insulation is held constant. It cannot be placed directly on a metal deck because of its flammability. A kraft paper type vapor barrier placed between the deck and insulation will allow use of the urethane or foam (Construction, 1970:51). Use of a vapor barrier can cause water to collect in the insulation layer, causing deterioration of the insulation. Currently, vapor barriers are not installed above metal decks (Construction, 1970:49). Fiberglass insulation can be used directly over a metal deck. Other insulation can be placed over the fiberglass. Rigid fiberglass, fifteen-sixteenths of an inch thick, topped with 1.25 inches of urethane was selected. This insulation combination gave the lightest weight, least costs, and thinnest cross section. Table C-4-2 illustrates the "R" value and weight for a four-ply roof with no insulation. The desired roof "U" value after analysis was 0.075. Since "R" is the inverse of U, the total "R" value desired for the roof is 13.33. Subtracting the value of 1.11 from this leaves 12.22, which is the "R" value that has to be obtained from the insulation. Table C-4-3 depicts weights and "R" values for

fiberglass and urethane. It also illustrates that the combination of fiberglass and urethane was thinner by an excess of one inch.

Table C-4-4 illustrates the comparison of two types of four-ply built-up roofing. The difference was in price. A four-ply built-up roof composed of felts, asphalt, and gravel was selected. The selected roofing is depicted in Table C-4-5. This selection was the lightest, yet strong enough to prevent ponding in the areas between purlins, while adequate slope, and desired insulation were provided. The selected roofing was the most economical to meet the criteria.

TABLE C-4-1

DECKS

MATERIAL	R * (°F/BTU/HR-SQ FT)	WEIGHT * (PSF)	COST ** ($/SQ FT)
2 In Gypsum Plank	3.1	11	1.35
2 In Concrete Plank	1.72	9	1.45
20 G Steel	0	2.3	0.90
1 In Fiberglass Insulation	4.1	0.8	0.38
20 G Steel & 1 In Insulation	4.1	3.1	1.28

TABLE C-4-2

ROOF WITHOUT INSULATION

MATERIAL	R * (°F/BTU/HR-SQ FT)	WEIGHT * (PSF)	COST ** ($/SQ FT)
Inside Air Film	0.61	---	----
20 G Steel Deck	----	2.3	0.90
4-Ply Built-Up Roof	0.33	6.2	0.51
Outside Air Film	0.17	---	----
Total	1.11	8.6	1.41

* Weights and "R" values from Carrier, 1972

** (Means, 1975)

TABLE C-4-3

RIGID INSULATION

MATERIAL	R * (^{o}F/BTU/HR-SQ FT)	WEIGHT * (PSF)	COST ** ($/SQ FT)
15/16 In Fiberglass	3.7	0.7	0.36
3-5/16 In Fiberglass	12.2	2.4	1.09
1 In Urethane	6.7	0.86	0.51
1.25 In Urethane	8.52	0.89	0.63
2 In Urethane	14.3	1.0	0.88
15/16 In Fiberglass Plus 1.25 In Urethane	12.22	1.59	0.99

TABLE C-4-4

FOUR-PLY BUILT-UP ROOF

MATERIAL	R * (^{o}F/BTU/HR-SQ FT)	WEIGHT * (PSF)	COST ** ($/SQ FT)
Felts, Asphalt, Gravel	0.33	6.3	0.51
Felts, Tar, Gravel	0.33	6.3	0.57

TABLE C-4-5

SELECTED ROOFING

MATERIAL	R * (^{O}F/BTU/HR-SQ FT)	WEIGHT * (PSF)	COST ** ($/SQ FT)
Inside Air Film	0.61	---	---
20 G Steel Deck	----	2.3	0.90
15/16 In Fiberglass	3.7	0.7	0.36
1.25 In Urethane	8.52	0.89	0.63
4-Ply Built-Up Roof With Felt, Asphalt, Gravel	0.33	6.3	0.51
Outside Air Film	0.17	---	---
Total	13.33	10.19	2.40

APPENDIX C-5

Spread Footing Design Appendix Symbols

As - Area of steel reinforcement

b_o - Periphery around loaded areas

b - Footing width

d - Effective footing depth

fc' - Allowable concrete compressive strength

fy - Steel yield stress

fb - Allowable nominal ultimate bearing stress

h - Base plate dimension

l - Effective moment arm

Ld - Development length

m - Ratio of fy to 0.85 fc'

Mu - Bending Moment

Pu - Total factored load

Pnet - Net earth pressure

Ru - Utimate strength coefficient

v_c - Allowable unit shear stress

v_u - Design unit shear stress

Vu - Shear force

W, W_D, W_L - Uniform load (D-dead, L-live)

ϕ - Reduction factor

P - Percentage of steel reinforcement

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APPENDIX C-5

DESIGN OF SPREAD FOOTINGS

Square spread footings were designed for interior column supports where gravity loads only were applied. The following loading cases were analyzed:

1. 60 feet by 60 feet column spacing - column load 142 kips
2. 60 feet by 36 feet column spacing - column load 126 kips

As an example of the design technique the 142 kip footing is analyzed below. The design steps are:

1. Factoring of dead and live loads
2. Design of footing dimensions
3. Shear stress analysis
4. Flexural analysis
5. Check of reinforcement bond
6. Costing

Assumptions. The following material properties were assumed:

1000 psf soil bearing capacity

fy = 40,000 psi

fc' = 3,000 psi

Loads. The total load of 142 kips comprised a dead load component of 70 kips and a live load of 72 kips. This load was made up of the roof and column loads for the 60 foot building. Loads for 30, 40, and 50 foot high buildings varied marginally from this and a single footing design was used for all building heights. The design load for use in footing design using ultimate strength theory is:

$Pu = 1.4\ W_D + 1.7\ W_L$ (ACI, 1971:26)

or $Pu = 1.4(70) + 1.7\ (72) = 220.4$ kips

Footing Dimensions. A square footing was designed for an allowable soil bearing capacity of 1000 pounds per square foot. Normal practice is to calculate an increased bearing capacity due to surcharge when the footing is placed below the surface. However, this was a function of the undefined soil properties and was assumed to be offset in this analysis by the actual footing weight. Therefore, the net soil bearing capacity was assumed to be 1000 pounds per square foot:

Required footing area = 142,000/1,000 = 142 sq ft

Footing size = $\sqrt{142} \simeq 12$ ft

The footing depth is a function of shear and flexural stresses. The required reinforcement cover is three inches under bottom steel (ACI, 1975: 21). An approximate footing thickness of 12 inches was selected to enter the analysis.

Shear Analysis. The footing was analyzed for both one-way and two-way shear stress. Figure C-5-1 shows dimensions used in this analysis.

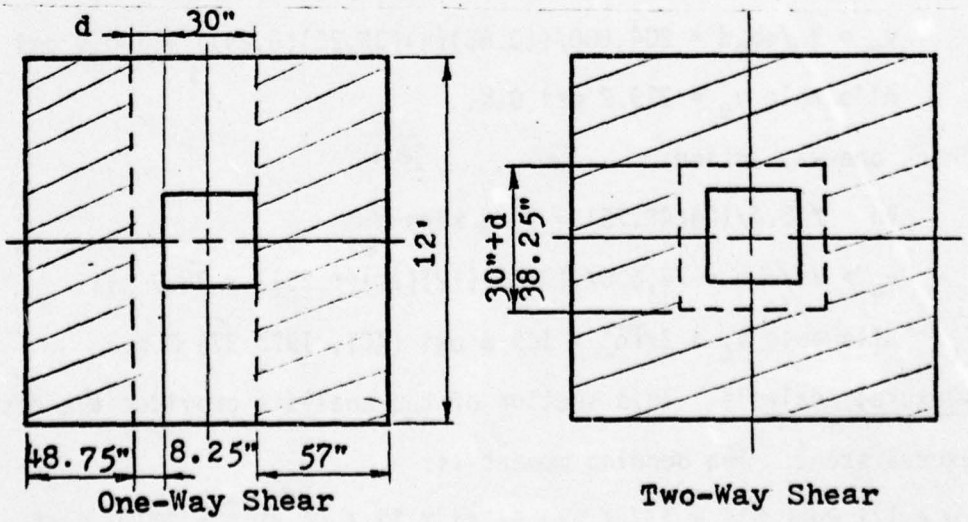


FIGURE C-5-1 FOOTING SHEAR CONDITIONS

For the analysis, a 30 inch square column base plate was assumed. In order to verify the assumed footing depth, a check of two-way shear to estimate depth was solved using:

$v_u = V_u/\phi b_o d$ (ACI, 1975:36)

or $d = Vu/\phi b_o v_u$

For an assumed thickness of 12 inches, the effective depth using #4 bars is:

$d = 12 - 3 - 0.5 = 8.5$ in

The shear force:

$Vu = Pnet$ (effective area) $= 220.4/144(12^2 - (38.5/12)^2) = 204.6$ kips

$v_u = 4\sqrt{fc'} = 219.2$ psi (ACI, 1975:40)

Required $d = Vu/\phi b_o v_u = 204{,}600/\{(0.85)(4)(38.5)(219.2)\} = 7.1$ in O.K.

As the reinforcement size may be greater than #4 bars, the footing will be analyzed for a thickness of 12 inches and estimated based on #6 bars.

Estimated $d = 12 - 3 - 0.75 = 8.25$ in

Check two-way action:

$Vu = 220.4/144(12^2 - (38.25/12)^2) = 204.8$ kips

$v_u = V_u/\phi b_o d = 204{,}800/\{(0.85)(4)(38.25)(8.25)\} = 190.9$ psi

Allowable $v_u = 219.2$ psi O.K.

Check one-way action:

$Vu = 220.4/144(48.75) = 74.6$ kips

$v_u = Vu/\phi bd = 74{,}600/\{(0.85)(12)(12)(8.25)\} = 73.9$ psi

Allowable $v_c = 2\sqrt{fc'} = 109.6$ psi (ACI, 1975:37) O.K.

Flexural Analysis. This section of the analysis provides the design of flexural steel. The bending moment is:

$Mu = 1/2\ Pnet\ bl^2 = 1/2 \times 220.4/144 \times 12 \times (4.75)^2 = 207.2$ k-ft

Required Ru = 1/2 Pnet bl^2 = 1/2 X 220.4/144 X 12 X $(4.75)^2$ = 207.2 k-ft

Required Ru = $Mu/\phi bd^2\{(0.9)(144)(8.25)^2\}$

$P = (1/m)(1 - \sqrt{1 - 2mRu/fy})$

$m = fy/0.85fc' = 40{,}000/\{(0.85)(3000)\} = 15.67$ (Wang, 1973:46)

So P = 0.0075

P min = 200/fy = 0.005 (ACI, 1975:31) O.K.

and As = Pbd = 0.0075 X 144 X 8.25 = 8.9 sq in

Using #6 bars the area of steel provided using 6 inch spacing is:

24(0.442) = 10.6 sq in O.K.

The steel is placed at 6 inch spacing in both directions. A check is also required for load transfer from the column to the footing. The nominal bearing stress is:

$fb = Pu/\phi h^2 = 220.4 \text{ X } 1000/\{(0.7)(30)^2\} = 351$ psi

Allowable fb = 0.85 fc' = 2550 psi (ACI, 1975:33) O.K.

Bond. The reinforcement must be embedded from the face of the column a distance equal to the development length Ld for #6 bars (ACI, 1975:43).

Ld (#6) = 12.8 in (ACI, 1975:43)

The development length provided is 4.75 feet less an assumed two inches cover and thus ample development length is available.

Costing. The resultant spread footing sizes are:

60 feet by 60 feet column spacing - 12 feet square by 12 inches deep

60 feet by 36 feet column spacing - 11 feet 6 inches square by 12 inches deep

Costing was based upon the facility life of 25 years and no maintenance costs have been included. Cost of reinforced concrete footings is $72 per cubic yard (Means, 1975:274).

Footing Load (Kips)	Footing Dimensions Length (Ft)	Breadth (Ft)	Depth (Ft)	Cubic Yards Per Footing	Total Cost	Annual Cost
142	12	12	1	5.3	$384	$42.30
126	11.5	11.5	1	4.9	$353	$38.90

APPENDIX C-6

Pile Supported Footing Appendix Symbols

- As - Area of steel reinforcement
- b - Width of slab
- b_o - Shear perimeter in two-way action
- d - Effective depth
- D - Dead loads
- f_c' - Allowable concrete stress
- f_y - Allowable steel yield stress
- L - Live loads
- M - Calculated bending moment
- Mwu - Applied wind design moment
- m - Ratio of $f_y/(0.85)f_c'$
- Pu - Axial design load
- p - Percentage of reinforcement steel
- R_A, R_B - Pile reactions
- Ru - Ultimate strength coefficient
- U - Required strength to resist design loads
- v_u - Unit shear stress
- v_c - Allowable unit shear stress
- V - Shear force
- W - Wind load
- w - Footing weight
- Φ - Reduction factor
- θ - Angle

APPENDIX C-6

PILE SUPPORTED FOOTINGS

Preliminary design of type 2 and 3 footings resulted in very large spread footings varying from 15 feet to 21 feet in length. The recommended maximum length for spread footings in the Norfolk area is less than 15 feet (McAndrews, 1976). An economical alternative to spread footings, where large wind induced moments were applied, was to use pile supported footings. The design steps for footing design were:

1. Evaluation of footing dimensions to provide adequate moment resistance for direct wind load.
2. Check footing dimensions to resist wind suction.
3. Check of footing dead plus live load capacity.
4. Design of footing for shear and flexure.
5. Costing of selected foundation.

The following sample calculations are for the design of a footing to support wind load in one direction for the 60 foot high building case. A summary of all results is included in the "Consolidated Cost Estimates" section.

Assumptions. The following values were assumed in the analysis:

1. Pile bearing capacity of 100 kips (McAndrews, 1976).
2. Pile tensile capacity of 50 kips (Nothnagel, 1976).
3. Concrete compressive strength, f_c' = 3,000 psi.
4. Steel yield strength, f_y = 40,000 psi.

Footing Dimensions. The selection of the footing length was based upon providing an adequate moment arm to resist the applied wind moments.

The minimum number of piles recommended is three (Gaylord, 1968:5-73). A three pile arrangement assures structural stability. The loading cases analyzed for all building heights were as follows:

Direct Wind Loads

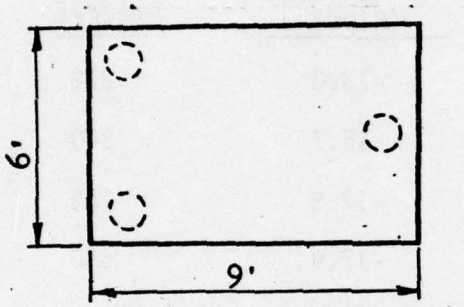
Building Height (Ft)	Corner Column Moment (K-Ft)	Corner Column * Axial Load (Kips)	Side Column Moment (K-Ft)	Side Column * Axial Load (Kips)
30	210	-13.0	212	-13.2
40	342	-15.7	340	-15.7
50	484	-17.8	485	-17.8
60	608	-17.9	650	-20.1
		Wind Suction		
30	105	+28.5	106	+28.4
40	171	+27.2	170	+27.2
50	242	+26.1	243	+26.1
60	304	+26.1	325	+25.0

* Sign Convention: Uplift force is negative.

Since equal tensile and compressive capacities could be achieved by using two tension piles and one compression pile, the column was designed to be approximately central to the footing. Preliminary analysis indicated that a length of seven feet between the tension and compression ends of the resisting couple was required. Allowing for pile width of ten inches and an overhang of about six inches, the actual footing length was nine feet.

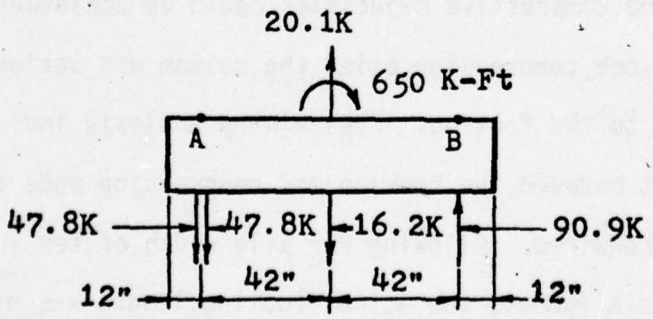
For stability, a minimum overall footing width of four feet was selected. The pile spacing for this dimension would be about two feet center to center and a reduced pile capacity would be required to allow

for group action. For the case analyzed here, maximum pile capacity was required to adequately resist the large moment. Spangler recommends a pile spacing of five pile diameters to ensure full pile capacity (Spangler, 1960:386). To provide this spacing for ten inch piles required a footing width of six feet allowing six inches overhang.



Pile Cap and Layout

Resultant forces for an assumed pile thickness of two feet are shown below. The analysis neglects weight of soil above the footing and any resistance provided by the building floor.



Footing weight w = 9 X 6 X 2 X 0.15 = 16.2 kips

Taking moments about B:

$(-R_A \times 7.0) + (16.2 \times 3.5) - (20.1 \times 3.5) - 650 = 0$

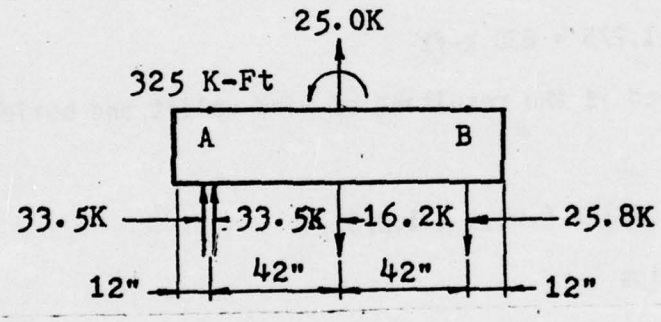
$R_A = -94.8$ kips

Taking moments about A:

$(R_B \times 7) + (20.1 \times 3.5) - (16.2 \times 3.5) - 650 = 0$

$R_B = +90.9$ kips

Wind Suction. A diagram of the selected footing showing forces for wind suction is presented. The resulting loads on the pile foundations were well within the allowable capacities.



Taking moments about B:

$325 + (25 \times 3.5) + (16.2 \times 3.5) - (R_A \times 7.0) = 0$

$R_A = 67.0$ kips O.K.

Taking moments about A:

$R_B = 25.8$ kips O.K.

Gravity Loads. Total gravity load, including snow live loads, for the 60 foot high building was 142 kips. The allowable bearing capacity for three piles is 300 kips. The piles are quite adequate for this load. The footing flexural capacity must also be checked and this is included in the following section.

Flexure and Shear. The minimum allowable thickness for a footing supported on piles is 12 inches above the tension reinforcement at the edge (ACI, 1975: 55). The minimum required cover for concrete in contact with soil is three inches (ACI, 1975: 21). Because of the large moment on the footing a total depth of two feet was selected.

Where wind and dead loads are analyzed using ultimate strength theory, loads must be factored as follows:

U = 1.05D + 1.275W (ACI, 1975: 26)

The moment is directly due to wind load, so that:

Mwu = m X 1.275

Mwu = 650 X 1.275 = 830 k-ft

The axial load is the resultant of wind uplift and building dead load.

Pu = (70 X 1.05) + (-90.1 X 1.275)

Pu = -41.4 kips

w = (16.2 X 1.05) = 17 kips

The resultant shear and moment diagrams for the factored loads assuming a conservative simple support system are shown.

Taking moments about B:

$(-R_A \times 7.0) + (17.0 \times 3.5) - (41.4 \times 3.5) - 830 = 0$

$R_A = -130.8$ kips

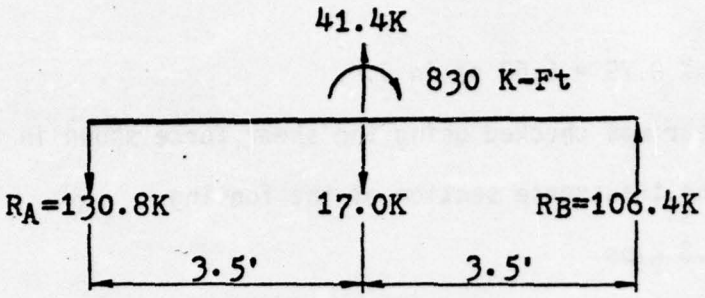
Taking moments about A:

$(R_B \times 7.0) + (41.4 \times 3.5) - (17.0 \times 3.5) - 830 = 0$

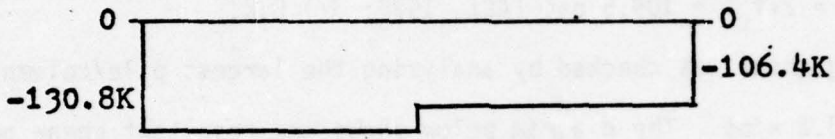
$R_B = +106.4$ kips

The maximum flexural moment is:

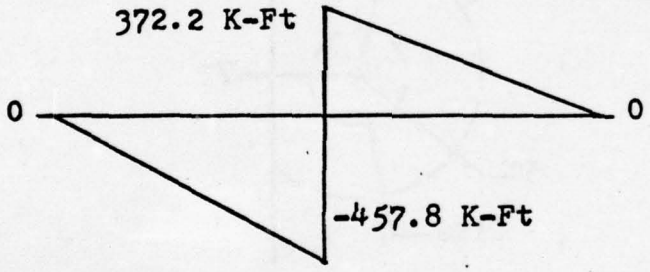
Mu = 130.8 X 3.5 = 457.8 k-ft



Loading Diagram



Shear Diagram



Moment Diagram

Required Ru = $Mu/\Phi bd^2$ (Wang, 1973:45)

Ru = 457.8 X 12,000/(0.9)(6)(12)$(20)^2$ = 212 psi

Where d is approximately 20 inches for a 24 inch slab thickness.

$p = (1/m)(1 - \sqrt{1 - 2mRu/f_y})$ (Wang, 1973:45)

$m = f_y/0.85\ f_c'$ = 40,000/(0.85)(3000) = 15.67

p = 0.0055

Required As = pbd = 0.0055 X 72 X 20 = 7.98 sq in

This area of steel can be provided using #8 reinforcing bars at six inch spacing.

(11 #8) X 0.79 = 8.69 sq in O.K.

Wide beam shear was checked using the shear force shown in the diagram carried through the transverse section of the footing.

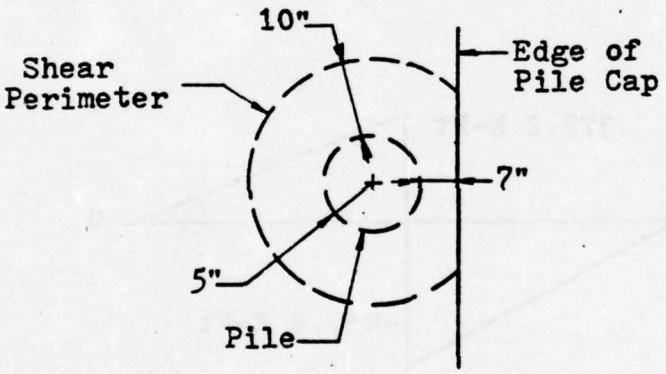
V = 130.8 kips

Unit shear $v_u = V/\Phi bd = 130.8 \times 1000/(.85)(6)(12)(20) = 106.9$ psi

Allowable shear with no shear reinforcement is:

$v_c = 2\sqrt{f_c'} = 109.5$ psi (ACI, 1975: 37) O.K.

Punching shear was checked by analyzing the largest pile/column reaction of 130.8 kips. The diagram below shows the resultant shear perimeter:



The angle subtended at the footing edge is:

$\theta = 2 \arccos (12/15) = 1.29$ radians

Shear perimeter is:

$b_o = (2\pi - 1.29)(15) = 74.94$ in

Unit shear is:

$v_u = V/\Phi b_o d = 130.8 \times 1000/(0.85)(74.94)(20) = 102.7$ psi

Allowable punching shear:

$v_c = 4\sqrt{f_c'} = 219$ psi (ACI, 1975: 37)

Finally the ability of the pile cap to resist sliding shear was checked.

As no pile capital was used the shear force was carried through three piles of 10 inch diameter.

Shear force = moment/moment arm = 830/60 = 14.8 kips

Area of piles = 3 X π X $(5)^2$ = 236 sq in

Unit shear = 13.8 X 1000/236 = 58.6 psi

Allowable shear, $v_c = 2\sqrt{f'_c}$ = 109.5 psi (ACI, 1975:37) O.K.

A check of the footing properties in resisting gravity loads only was required. The factored gravity loads were:

$$Pu = 1.4D + 1.7L = 1.4(70) + 1.7(72) = 220.4 \text{ kips}$$

Assuming simple supports, the resultant moment at the center of the footing is:

$$M = 220.4/2 \text{ X } 3.5 = 386 \text{ k-ft}$$

This is a conservative estimate of the bending moment. As it is less than the maximum moment resulting from wind load the footing is adequate for direct gravity loads.

The requirement for transverse reinforcement was also considered. Applied moment in the transverse direction was difficult to assess because of the pile arrangement. However, the maximum moment possible was that resulting from applying the column gravity loads along the line of the two transverse piles. As the moment arm for this case was less than for the longitudinal case, the resultant moment was less and the same steel layout as used in the longitudinal direction was considered quite adequate.

The required development length for #8 bars is 23.1 inches (Wang, 1973: 198). The length provided in the longitudinal direction was 54 inches less about two inches cover and in the transverse direction, 36 inches less two inches cover. This satisfies development length criteria.

Costing. The capital cost of footings was estimated using a pile cost of $4.50 per linear foot (McAndrews, 1976) and a footing cost of $72.00 per cubic yard (Means, 1975:276). Capital costs were converted to annual costs using a ten percent interest rate and a zero salvage value after 25 years. The following is a summary of footing dimensions and foundation costs for all cases. Foundations in the corner areas of the building were based upon four piles because of the need to carry moment in two directions.

TABLE C-6-1

SUMMARY OF FOOTING DIMENSIONS AND FOUNDATION COSTS

BUILDING HEIGHT (FT)	FOOTING TYPE	DIMENSIONS LENGTH (FT)	WIDTH (FT)	DEPTH (FT)	PILE COST	SLAB COST	TOTAL COST
60	2	9.0	6.0	2.0	$675	$288	$963
50	2	7.5	5.0	2.0	$675	$200	$875
40	2	6.0	4.0	2.0	$675	$128	$803
30	2	5.0	4.0	2.0	$675	$107	$782
60	3	9.0	9.0	2.0	$900	$432	$1332
50	3	7.5	7.5	2.0	$900	$300	$1200
40	3	6.0	6.0	2.0	$900	$192	$1092
30	3	5.0	5.0	2.0	$900	$133	$1033

APPENDIX C-7

Exterior Wall Footing Appendix Symbols

ϕ - Angle of internal friction

δ - Unit weight of soil

c - Cohesion of the soil

q - Allowable soil bearing capacity

h - Height of soil layer

Ka - Active-earth-pressure coefficient

Pt - Lateral force of the soil

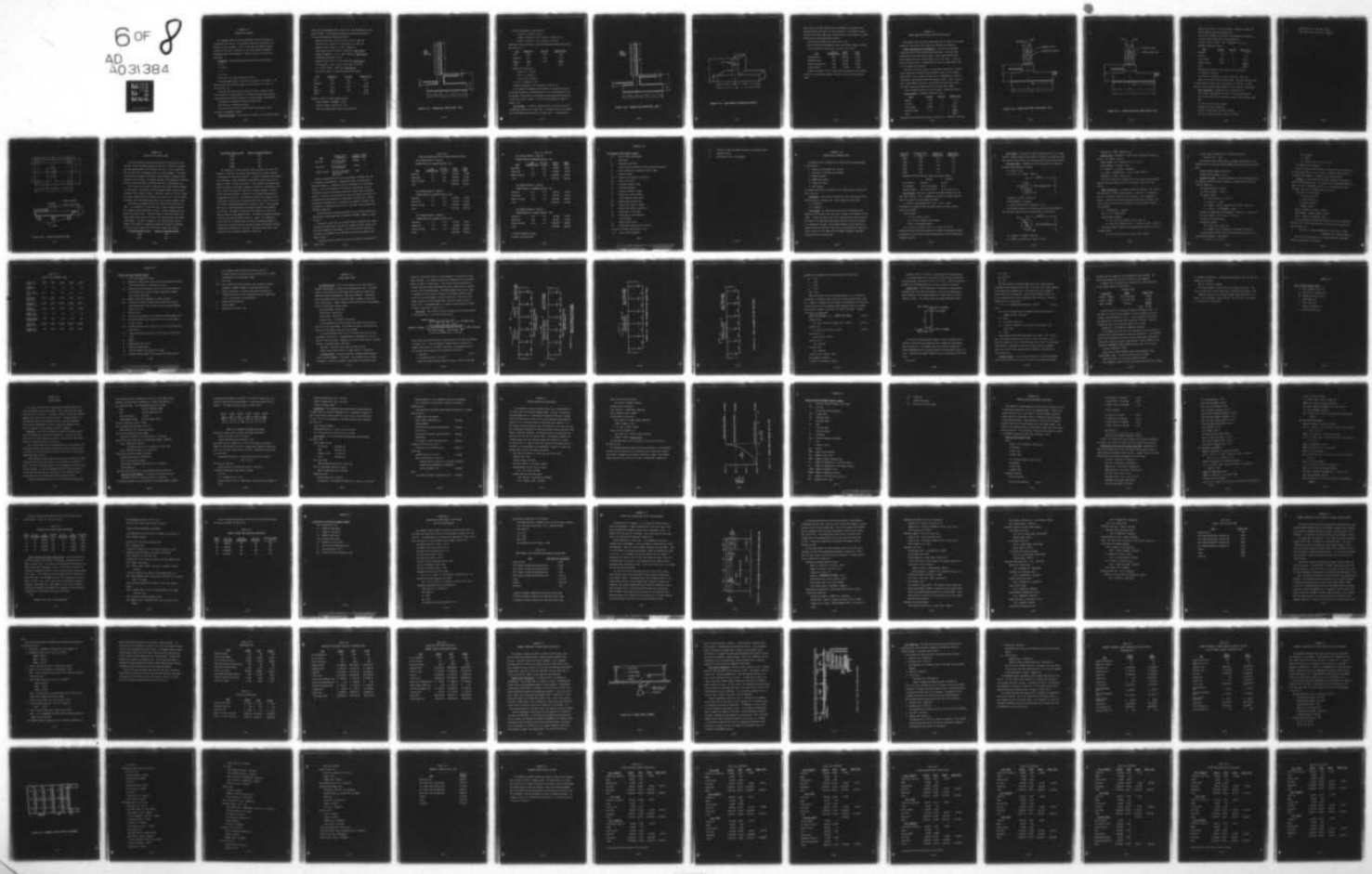
X - Moment arm of resultant acting through the base of the footing

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A GENERAL WAREHOUSE MODULE CONCEPTUAL DESIGN AND COST ANALYSIS.--ETC(U)
SEP 76 R T ALEXANDER, T J CARMICHAEL

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APPENDIX C-7

EXTERIOR WALL FOOTING

This appendix shows the design calculations and cost estimates for the exterior wall footing. The assumptions used are listed and the two loading cases are presented. Case 1 is the wind load blowing directly on the wall while Case 2 accounts for the suction pressure created on the leeward side of the structure. Finally, the cost of the footing is calculated.

Assumptions. The following properties were used for the design:

$\phi = 30^{o}$

$\delta = 110$ pcf

$c = 0$

$q = 1.0$ ksf

Frost line = 10 in below the ground surface

The design model shown in Figure C-7-1 was used to study Case 1. The footing is one foot below the ground surface to insure it is below the 10 inch frost line.

Since the wind forces acting on the wall produce a moment similar to soil acting on a retaining wall, the design procedures used to design a retaining wall were used to design this footing (Bowles, 1968:338-341).

The footing is assumed to be above the water table.

The footing is a continuous footing.

The live load in the floor section around the perimeter of the structure was assumed to be zero.

Design Calculations. After several iterations, using different footing

widths, the design model shown in Figure C-7-1 was determined to be the most efficient. The following calculations show how the dimensions of the wall footing were checked for Case 1.

Weight of tilt slab = 7.5/12 X 1 X 20 X .150 = 1.875 k/ft

Weight of wall insulation = 1.5/12 X 20 X 6 = 0.015 k/ft

Weight of steel siding = 1.4 X 20 = 0.028 k/ft

Total weight of tilt slab wall = 1.918 k/ft Use 2.0 k/ft

Weight of pedestal = 1 X 5 X .150 = 0.75 k/ft Use 0.75 k/ft

Estimated footing base = 13 ft

Weight of base = 13 X 2 X .150 = 3.90 k/ft Use 3.90 k/ft

Soil pressure = δ hKa = .110 X 5.33 X 0.333 = 0.195 ksf

Pt = 0.195 X 5.33/2 = 0.520 k/ft Use 0.52 k/ft

The force Pt acts 2 ft above the base of the footing

Part	Weight (k)	Arm (ft)	Moment (k-ft)
Wall	2.00	8.50	17.0
Pedestal	0.75	8.50	6.38
Base	3.90	6.50	25.35
Soil	0.52	2.00	1.04
Total	7.17		49.77

Determine factor of safety against overturn:

Overturn moment = 0.853(16) = 13.73

Factor of safety = 49.77/13.73 = 3.62

Factor of safety greater than 1.5, therefore O.K.

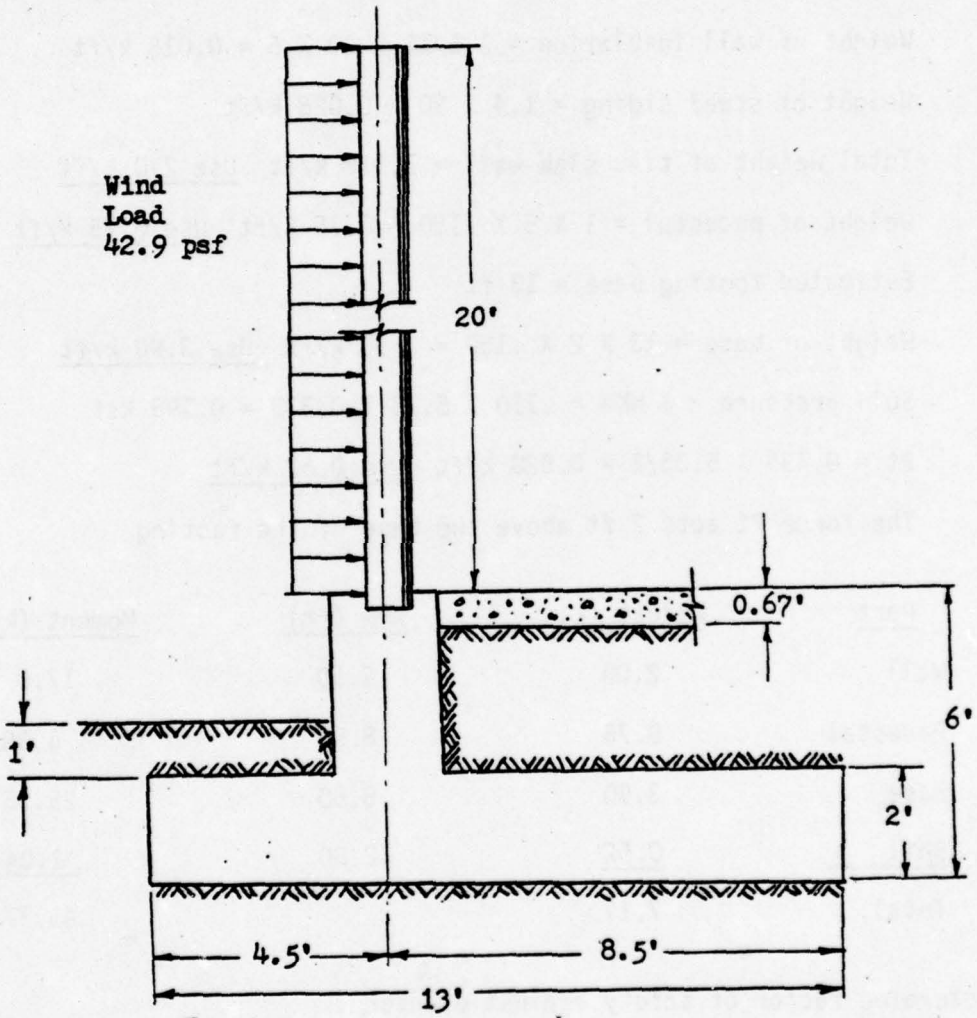


FIGURE C-7-1 EXTERIOR WALL FOOTING MODEL, CASE 1

Insure toe pressure is less than 1.0 k

$X = 49.77 - 13.73/7.17 = 5.03$

$q\ (max) = 7.17/13\ \{1 + (6 \times 1.47)/13\} = 0.93$ ksf O.K.

$q\ (min) = 7.17/13\ \{1 - (6 \times 1.47)/13\} = 0.18$ ksf

Check Case 2 for toe pressure, since the toe pressure governs the design. See Figure C-7-2.

Part	Weight (k)	Arm (ft)	Moment (k/ft)
Wall	2.00	4.50	9.00
Pedestal	0.75	4.50	3.38
Base	3.90	6.50	25.35
Total	6.65		37.73

Moments for overturn are:

$0.440 \times 16 = 7.04$ k/ft

$0.52 \times 2 = 1.04$ k/ft

$7.04 + 1.04 = 8.08$ k/ft

$X = 37.73 - 8.08/6.65 = 4.46$

$q\ (max) = 6.65/13\ \{1 + (6 \times 2.04)/13\} = 0.99$ ksf O.K.

It is assumed that adequate reinforcement in the concrete base can be achieved; therefore, a detailed design of the reinforcement will not be included. The exterior wall footings develop enough bearing capacity to carry the exterior columns. The final footing design is shown in Figure C-7-3.

Cost Estimate. In order to calculate costs, an initial cost will be developed in dollars per linear foot. The capital cost of the footing will be developed and converted to an annual cost. To determine the

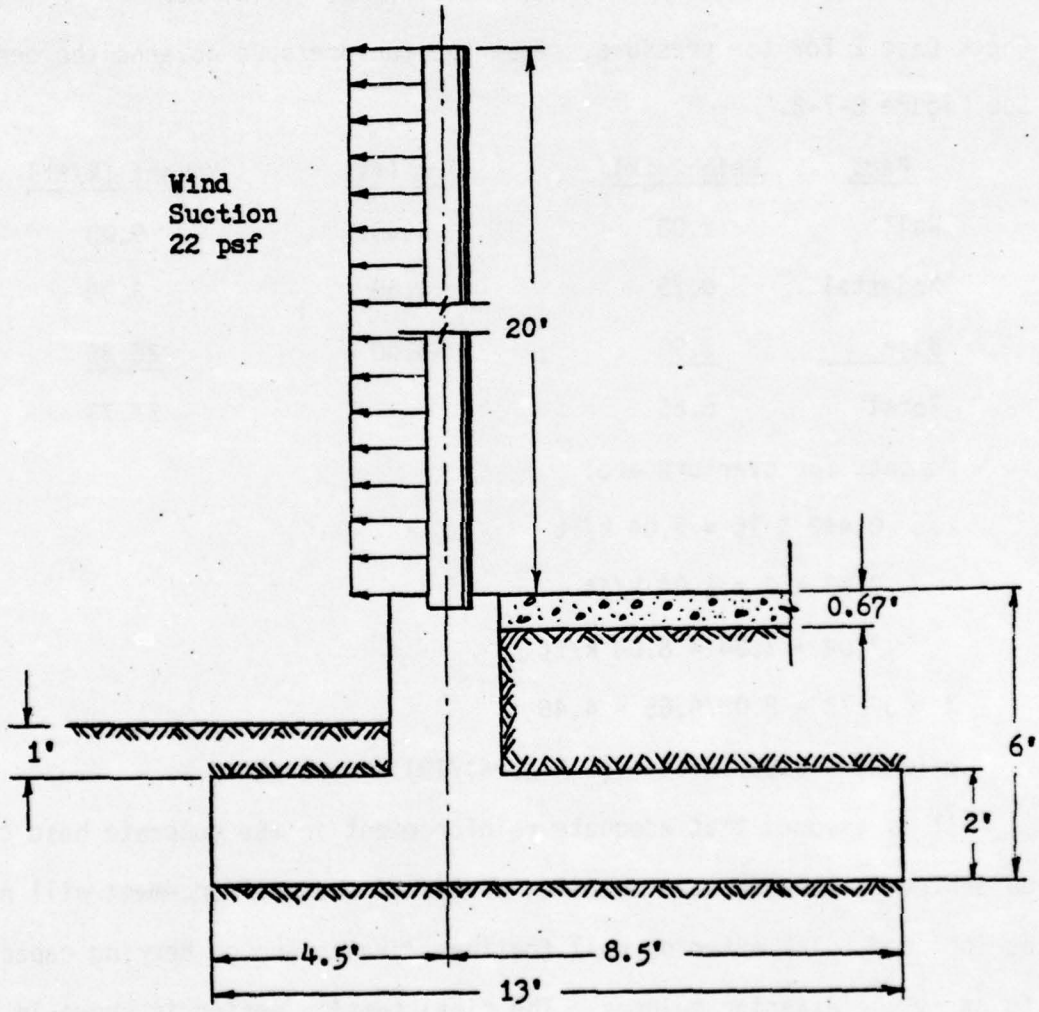


FIGURE C-7-2 EXTERIOR WALL FOOTING MODEL, CASE 2

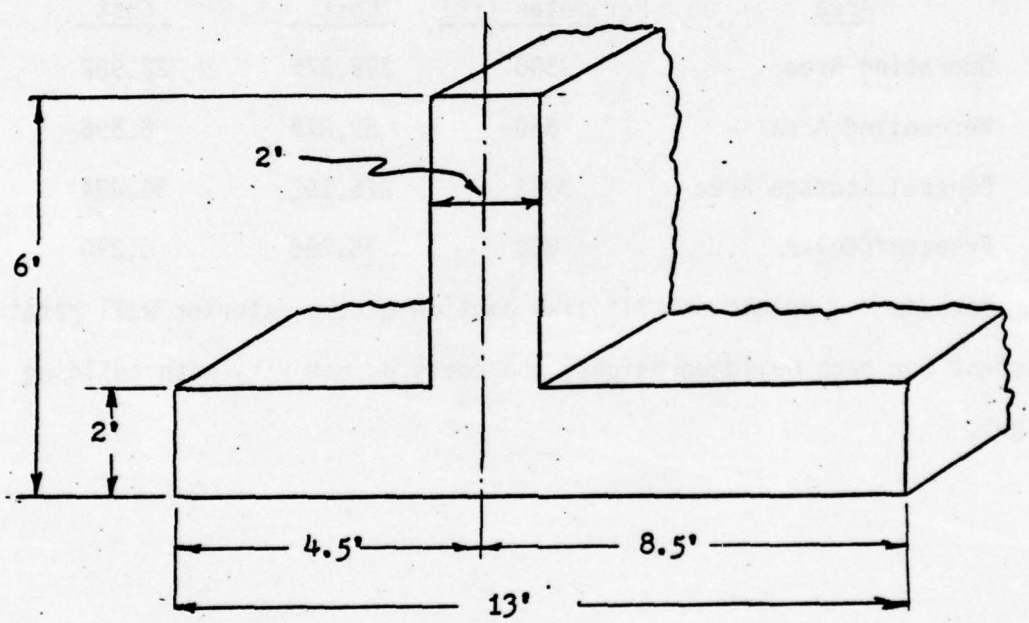


FIGURE C-7-3 FINAL DESIGN OF EXTERIOR WALL FOOTING

annual cost it has been assumed that no maintenance is required on the footings during the 25 year life of the structure. A 10 percent interest rate was used in the annual cost calculation and it was assumed the footing would have no salvage value after 25 years.

Cubic yards of concrete per linear foot = 1.26

Cost of reinforced concrete per cubic yard = $72.00 (Means, 1975:274)

Cost of footing per linear foot = 72.00 X 1.26 = $90.72

Area	Footing Perimeter (ft)	Capital Cost	Annual Cost
Operating Area	3300	299,376	32,982
Mechanized Area	660	59,875	6,596
General Storage Area	3044	276,152	30,424
Freezer/Cooler	830	75,298	8,296

Because the height of tilt slab portion of the exterior wall remains constant for each building height, the costs do not vary with building height.

APPENDIX C-8

BRIDGE CRANE FOOTING DESIGN AND COST CALCULATION

This appendix describes the footing design for the bridge crane system. In addition, the cost for the bridge crane footings are presented.

Design Considerations and Assumptions. The footing was designed to take the loads from the bridge crane and columns. The large loads created by the crane and columns require a large spread footing which would interfere with the railroad tracks in the train shed. In order to keep the footing size to a minimum and still meet the large design loads, a pile foundation was required.

The loads for the two critical loading cases considered in designing these footings were obtained from the computer analysis of the bridge crane system. Case 1, shown in Figure C-8-1, investigates the effect of maximum wind load and dead load on the exterior column. Case 2, shown in Figure C-8-2 considers only the live and dead roof load on the column. Both cases include the maximum load on the bridge crane column.

It was assumed that each pile would develop a capacity of 100 kips.

Design Analysis. Determine loading for Case 1.

Item	Load (k)	Arm (ft)	Moment (k-ft)
Pedestal	0.90	4	3.6
Pile Cap	3.00	5	15.0
Crane Column	315.00	5	1575.0
Exterior Column	------	-	576.0
Total			2169.6

Determine the reaction on the interior pile row: R = 2169.6/10 = 217 kips

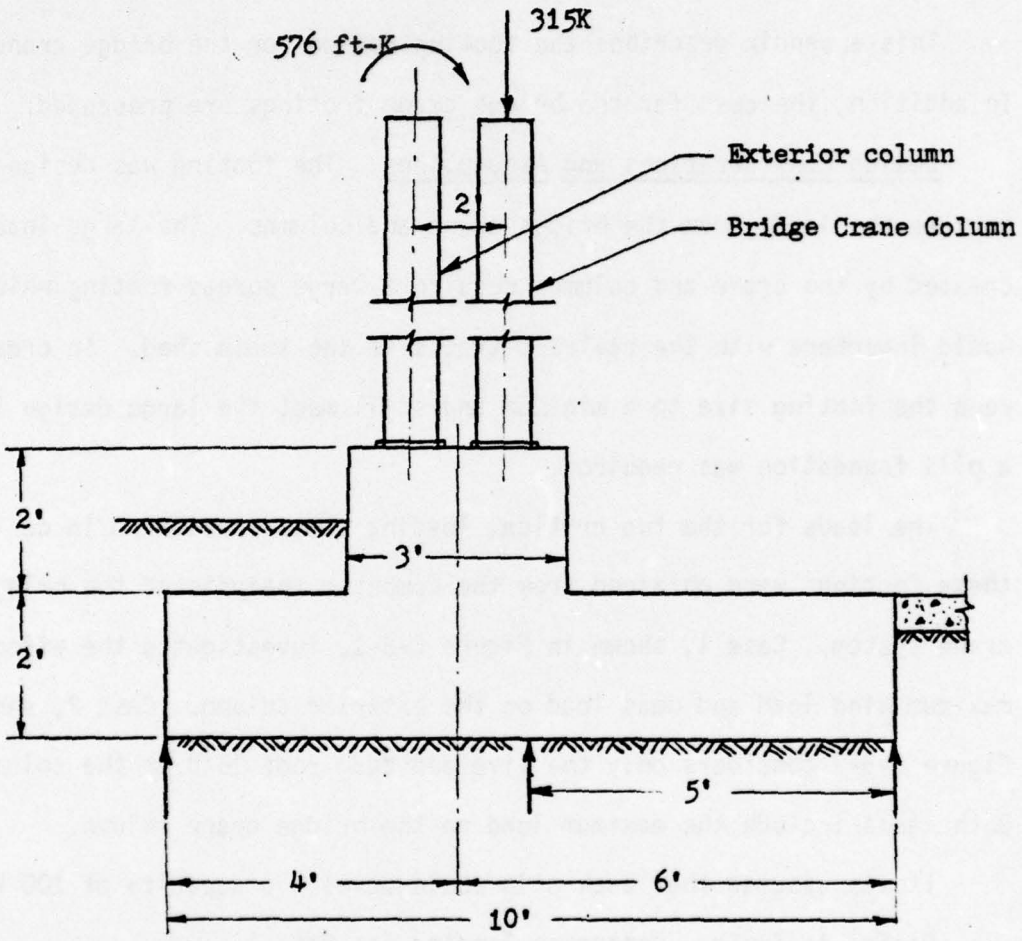


FIGURE C-8-1 BRIDGE CRANE FOOTING DESIGN MODEL, CASE 1

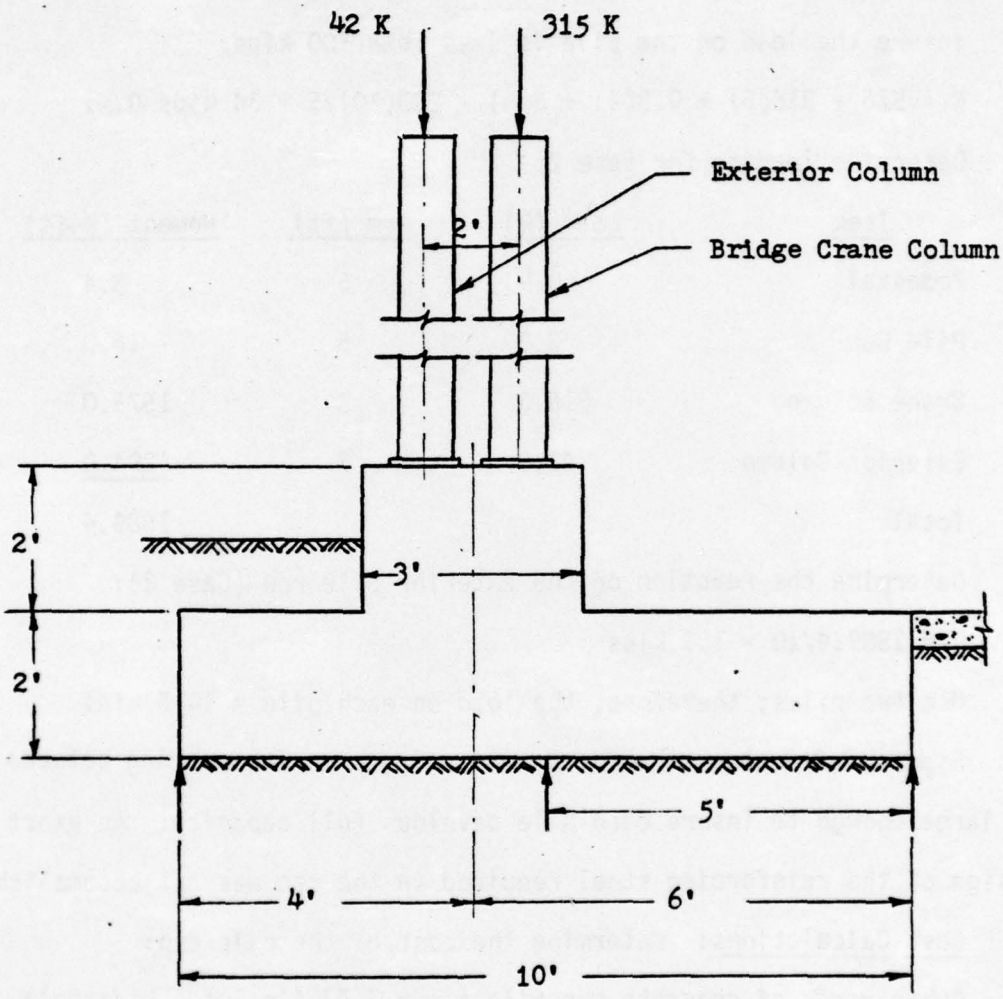


FIGURE C-8-2 BRIDGE CRANE FOOTING DESIGN MODEL, CASE 2

200 kips of the load is taken by 2 piles. Therefore, another pile must be added to take the remaining load.

Try one pile located at the center of the foundation and check to insure the load on the pile is less than 100 kips.

R = 576 + 315(5) + 0.9(4) + 3(5) - 200(10)/5 = 34 kips O.K.

Determine loading for Case 2:

Item	Load (k)	Arm (ft)	Moment (k-ft)
Pedestal	0.9	6	5.4
Pile Cap	3.0	5	15.0
Crane Column	315.0	5	1575.0
Exterior Column	42.0	7	294.0
Total			1889.4

Determine the reaction on the exterior pile row (Case 2):

R = 1889.4/10 = 189 kips

Use two piles; therefore, the load on each pile = 94.5 kips

Figure C-8-3 shows the final design layout. The spacing between piles is large enough to insure each pile develops full capacity. An exact design of the reinforcing steel required in the cap was not accomplished.

Cost Calculations: Determine the cost of the pile cap:

Cubic yards of concrete per pile cap = 7.77 (includes pedestal)

The cost per cubic yard of reinforced concrete = $72.00 (Means, 1975: 274)

The cost of the pile cap = $559.00

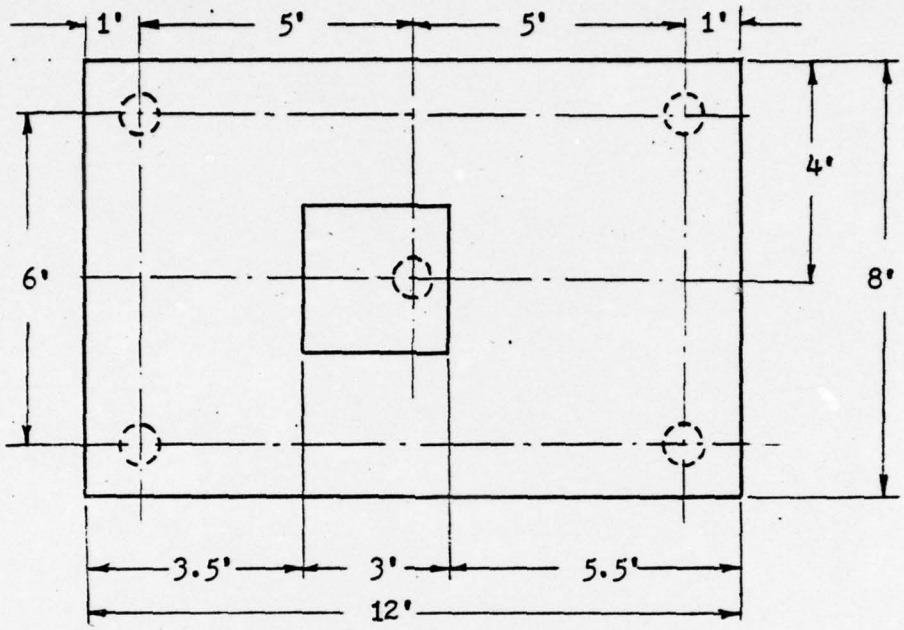
Determine the cost of the piles:

The cost of each pile = 4.50 X 50 = $225.00

The cost of pile per footing = 225 X 5 = $1125.00

Determine the total cost each footing:

Total capital cost per footing = $1684.00



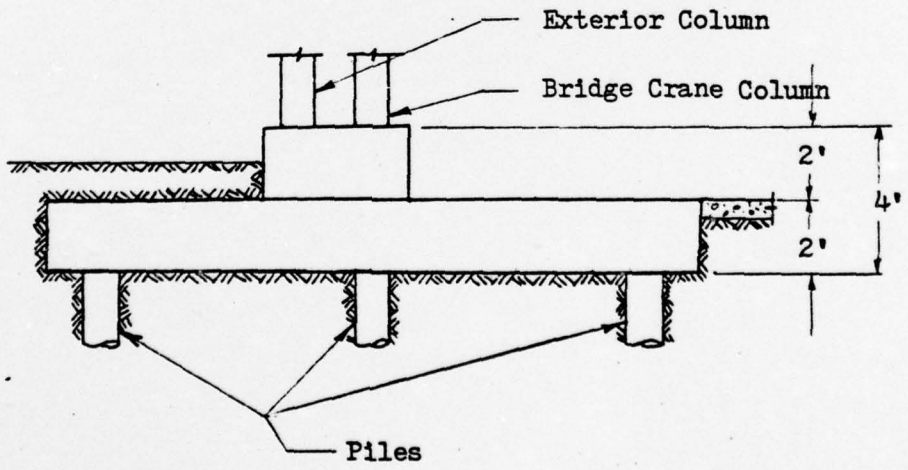


FIGURE C-8-3 BRIDGE CRANE FOOTING DESIGN

APPENDIX C-9

DESIGN OF SLAB FLOOR ON GRADE

The major assumption governing the design of a concrete slab floor on grade is that the bearing capacity of the soil is equal to or greater than the combined dead and live load of the floor. If this condition is met, the slab floor is designed similar to a rigid pavement. The factors that affect the thickness of the floor are the flexural strength of the concrete, the soil modulus of subgrade reaction, the frequency and intensity of wheel loads on the slab, and whether the slab is reinforced or not.

The thickness of the slab is governed by the 28 day flexural strength of the concrete. The required thickness becomes thinner as the flexural strength of the concrete increases. Generally, values of flexural strength of concrete range from 550 to 800 pounds per square inch. For this study an assumed value of 650 pounds per square inch was used (Hokanson, 1976).

The modulus of subgrade reaction also affects the thickness of the slab. It is important to stress that prior to actual design, accurate soil properties must be obtained in order to insure an adequate and economical slab floor design. Since the modulus of subgrade reaction can change significantly over the 50 acres, the slab design may also change significantly. In order to accomplish a preliminary design, typical values for the modulus of subgrade reaction were assumed to correspond to the soil bearing capacities listed below (Singh, 1967:70,551):

Soil Bearing Capacity (psi)	Modulus of Subgrade Reaction
1,000	150
2,000	200

Soil Bearing Capacity (psi)	Modulus of Subgrade Reaction
3,000	300
4,000	300
6,000	400
8,000	500

The frequency of traffic and wheel loads also govern the slab floor thickness. Generally as the wheel loads become heavier and/or increase in frequency, the slab must be thicker. In order to establish the thickness, it was necessary to make assumptions concerning the wheel loads and frequency of traffic in each of the areas. It was assumed the operating area would be subject to the highest frequency of traffic to include heavy fork lifts. Much of the area will make use of conveyor equipment. Because of the high ceiling heights, a portion of the conveyor load may have to be supported by the floor. The mechanized area was also assumed to have a high level of activity to include heavy fork lifts. Much of this area will contain automated equipment such as stacker cranes. It was assumed that the live loads generated by the stacker cranes will be supported by the floor. The general storage area was assumed to be less active than the operating and mechanized areas. The general storage was designed for heavy live loads and moderate activity. Again it is important to stress that prior to actual design, the material handling equipment locations must be specified and an accurate frequency and intensity of wheel loading must be provided for each area. The design indexes used in the calculations are listed below (AFM 88-7, 1969:1-13):

Area	Assumed Traffic Category	Assumed Frequency	Design Index
Operating	35 kip fork lifts (or equivalent)	100/day	10
Mechanized	35 kip fork lifts (or equivalent)	40/day	9
General Storage	120 kip track laying vehicles or 35 kip fork lifts	4/day	7

Another item governing the floor slab thickness is whether the slab is reinforced or nonreinforced. Nonreinforced slabs are usually more economical; however, a reinforced slab was considered for the following reasons. First, the thickness of the slab can be reduced by using reinforcement and the spacing between contraction joints can be increased. Second, if cracking of the slab were to occur, the width of the cracks are controlled and load transmission is maintained at a high level. Finally, differential settlement due to non-uniform soil support is reduced. Non-uniformity is a definite possibility for a slab over a large surface area (AFM 88-7, 1969:1-19).

Using the factors previously mentioned, the floor slab thickness was determined by using design charts contained in AFM 88-7, Chapter 1, pages 14 and 21.

The initial cost of the slab includes the cost of material and installation for the slab itself, the cost of finishing the floor surface, and the cost of applying a dust sealer. The initial cost was converted to an annual cost assuming a zero maintenance cost and zero salvage value after 25 years.

The design and cost results are given for various soil properties in Table C-9-1.

TABLE C-9-1

FLOOR SLAB DESIGN AND COST FOR VARIOUS BEARING CAPACITY

SOIL BEARING CAPACITY = 1000 PSI

ASSUMED MODULUS OF SUBGRADE REACTION = 150

AREA	SLAB THICKNESS (IN)	COST PER * SQ FT	INITIAL COST	ANNUAL COST
Operating	8.0	1.40	650,160	71,628
Mechanized	8.0	1.40	609,840	67,186
General Storage	7.0	1.26	1,646,568	181,402
Total			2,906,568	320,217

SOIL BEARING CAPACITY = 2000 PSI

ASSUMED MODULUS OF SUBGRADE REACTION = 200

Operating	8.0	1.40	650,160	71,628
Mechanized	7.5	1.33	579,348	63,827
General Storage	6.5	1.18	1,542,024	169,885
Total			2,771,532	305,340

SOIL BEARING CAPACITY = 3000 PSI

ASSUMED MODULUS OF SUBGRADE REACTION = 300

Operating	7.5	1.33	617,652	68,047
Mechanized	7.0	1.26	548,856	60,467
General Storage	6.0+	1.11	1,450,548	159,807
Total			2,617,056	288,321

TABLE C-9-1 CONTINUED

SOIL BEARING CAPACITY = 4000 PSI

ASSUMED MODULUS OF SUBGRADE REACTION = 300

AREA	SLAB THICKNESS (IN)	COST PER * SQ FT	INITIAL COST	ANNUAL COST
Operating	7.5	1.33	617,652	68,047
Mechanized	7.0	1.26	548,856	60,467
General Storage	6.0+	1.11	1,450,548	159,807
Total			2,617,056	288,321

SOIL BEARING CAPACITY = 6000 PSI

ASSUMED MODULUS OF SUBGRADE REACTION = 400

Operating	6.5	1.18	547,992	60,372
Mechanized	6.0+	1.11	483,516	53,269
General Storage	6.0+	1.11	1,450,548	159,807
Total			2,482,056	273,448

SOIL BEARING CAPACITY = 8000 PSI

ASSUMED MODULUS OF SUBGRADE REACTION = 500

Operating	6.0+	1.11	515,484	56,791
Mechanized	6.0+	1.11	483,516	53,269
General Storage	6.0+	1.11	1,450,548	159,807
Total			2,449,548	269,861

+ Minimum Allowable Thickness

* (Means, 1975:60,62,274)

APPENDIX C-10

Pile Supported Floor Appendix Symbols

As - Area of steel reinforcement

b - Slab width

b_w - Equivalent beam width

C - Cross sectional constant to define torsional properties

c_2 - Size of equivalent rectangular column capital

d - Effective depth

Ecs, E - Concrete slab modulus of elasticity

fy - Steel yield stress

fc' - Allowable concrete stress

Kt - Torsional stiffness

Kb - Flexural stiffness of beam

Lc - Clear span in long direction

l_2 - Total transverse span length

Mu - Moment under factored load

$\overline{Mu}$ - Theoretical flexural strength

m - Stress ratio equal to fy/0.85 fc'

Ru - Coefficient of resistance

Sc - Clear span in short direction

t - Slab thickness

v_u - Nominal shear stress

Vu - Design shear load at critical section

W, W_D, W_L - Uniform load (D-dead, L-live)

x, y - Cross section dimension

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β_s - Fraction of panel perimeter continuous with adjacent panels

ϕ - Reduction factor

p - Percentage of steel reinforcement

APPENDIX C- 10

DESIGN OF PILE SUPPORTED FLOOR

The design of pile supported floor involved the following sequence of calculations:

1. Selection of acceptable pile spacing
2. Selection of allowable slab thickness
3. Design for shear
4. Moment distribution
5. Design for flexure
6. Cost analysis

The design calculations included are for the 2000 pounds per square foot floor load case.

Assumptions. The principle assumption for the slab design was that the floor acts as a two-way slab. Other properties assumed were:

fy = 40,000 psi

fc' = 3,000 psi

Pile Spacing. Pile spacing was based upon the assumed bearing capacity of 50 tons/pile (100 kips) and an assumed slab thickness of nine inches. A check was made of the loss of capacity due to group action of piles and for the 8000 pounds per square foot floor load this resulted in a reduced pile spacing. The procedure adopted for this case was to reduce the bearing capacity of each pile by one-sixteenth for every pile within a radius of five times the pile diameter (Spangler, 1960:386). The resultant pile spacings were:

Floor Load (psf)	Max Pile Spacing (ft)	Assumed Pile Spacing (ft)	Adjusted Pile Spacing (ft)
2,000	6.88	6.5	6.5
3,000	5.67	5.5	5.5
4,000	4.93	4.5	4.5
6,000	4.04	4.0	4.0
8,000	3.50	3.5	3.0

Reduction for 8000 pounds per square foot (group action):

	Assumed	Revised
Pile Capacity	100 kips	75 kips
Pile Spacing	42 in(< 50 No Good)	36 in
Diagonal Spacing	59 in(> 50 in O.K.)	51 in(> 50 in O.K.)

Slab Thickness. ACI 9.5.3.1 specifies a minimum thickness for flat slabs (ACI, 1975:28). This is adapted for the case of no beams along the sides of the panel as follows (Wang, 1973:630):

$$t \geq Lc\{0.8 + 0.2(f_y/40{,}000)\}/36 - 2.5(1 - \beta_s)(1 + Lc/Sc)$$

Furthermore, flat slabs without drop panels must be at least 5 inches thick (ACI, 1975:28).

In the formula:

$Lc = 6.5 - 10/12 = 5.67$ ft

$\beta_s = 1$ (for an internal floor section)

$Lc/Sc = 1$ (for square panels)

So $t \geq 5.67(.8 + .2)/\{36 - 2.5(1 - 1)\} = .157$ ft = 1.9 in

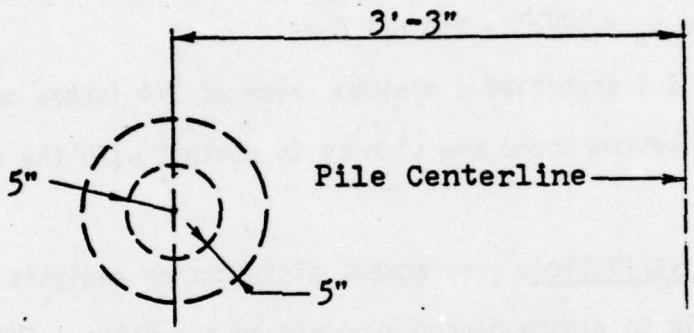
Because of the very small pile spacing this formula for deflection control was expected to give a small required thickness and so the 5 inch minimum thickness controls.

Shear Design. The design for shear includes provision for a column capital. However, because of the small pile spacing, no capital was used. Shear design included checks for wide beam action and for punching shear.

Wide Beam Action. Assuming a 6 inch slab thickness (to allow for concrete cover) the design load was:

$W = 1.4\ W_D + 1.7\ W_L$

$W = 1.4\ (75) + 1.7\ (2000) - 3505$ psf

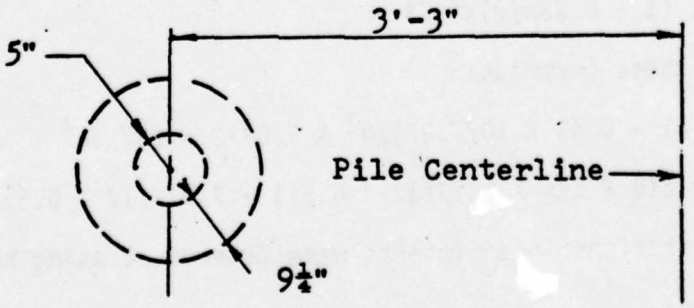


Allowable $v_u = 2\sqrt{f'c} = 109.54$ psi

So the required $d = Vu/\Phi b_w v_u$

$d = 3505 \times 2.417/(.85 \times 12 \times 109.54) = 7.6$ in

The assumed thickness was insufficient and a revised thickness of 10 inches was selected giving an approximate d of 9.25 inches.



$W = 1.4(125) + 1.7(2000) = 3575$ psf

$v_u = 3575 \times 2.10/(.85 \times 12 \times 9.25) = 79.6$ psi

Allowable $v_u = 2\sqrt{fc'} = 109.5$ psi O.K.

Two-Way Action. Assuming 0.75 inches cover and #5 bars the actual d is (10 - .75 - .625/2) = 8.94 in

Shear diameter = 10 + 2(8.94) = 27.9 in = 2.32 ft

Shear perimeter = $\pi(2.32) = 7.3$ ft

$Vu = 3575\{6.5^2 - \pi(2.3)^2/4\} = 135{,}890$ lb

$v_u = Vu/\Phi bd = 135{,}890/(.85 \times 7.3 \times 12 \times 8.94) = 204$ psi

Allowable $v_u = 4\sqrt{fc'} = 219$ psi O.K.

ACI 7.14.1.1 specified a minimum cover of 3/4 inches on top and three inches at the bottom where the slab is in contact with the soil (ACI, 1975:21).

Moment Distribution. For moment distribution analysis it was considered reasonable to assume pinned supports on the piles. This method results in a conservative design as pile stiffness is not accounted for. However, a contribution from slab torsional stiffness was included. ACI 13.4.1.5 defines the method of accounting for slab torsional stiffness (ACI, 1975:49):

$$Kt = \Sigma\ (9EcsC)/\{l_2(1 - c_2/l_2)^3\}$$

and $C = \Sigma\ (1 - 0.63x/y)x^3y/3$

Applying these formulas:

$C = (1 - 0.63 \times 10/7.07)10^3 \times 7.07/3 = 257$ in^4

$Kt = 2\{9 \times Ecs \times 257/\{12 \times 6.5(1 - 7.07/(12 \times 6.5))^3\} = 78.9$ Ecs

Relative stiffness coefficients were determined using Kb = 4 Ecs I/L for beam action:

$Kb = (4 \times Ecs/12 \times 6.5)(6.5 \times 12/12 \times 10^3) = 333$ Ecs

So that transfer coefficients for the beam action are:

Kb/Kt X Kb X 2 = .447

Using these transfer coefficients, the moment distributions to give maximum positive and maximum negative moments were analyzed and the results were:

Maximum negative moment = 101.3 k-ft

Maximum positive moment = 75 k-ft

Design For Flexure. The derived moments were used to design positive and negative reinforcing steel as follows. Assuming #5 steel bars the effective depth was:

For negative moment d = 8.31 in

For positive moment d = 6.06 in

For negative moment:

$\overline{M}u = Mu/\Phi = 101.3/.9 = 112/6$ k-ft

$m = fy/.85\ fc' = 15.69$

$Ru = Mu/bd^2 = 112.6 \times 12{,}000/(6.5 \times 12 \times 8.3^2) = 250.7$ psi

$p = (1/m)(1 - \sqrt{1 - (2mRu/fy)} = .0066$

Minimum p for temperature reinforcement = .002 bt or = .0024 bd O.K.

As = pbd = .0066 X 6.5 X 12 X 8.3 = 4.28 sq in

Use #5 bars @ 6 inch spacing.

For positive moment:

$Mu = Mu/\phi = 75/.9 = 88.3$ k-ft

$Ru = Mu/bd^2 = 83.3 \times 12{,}000/(6.5 \times 12(6.06)^2) = 348.7$ psi

It was evident here that larger reinforcing bars would result in a more effective spacing. Using #8 bars:

d = 10 - 3 - 1.5 = 5.5 in

Ru = 423.6 psi

p = .0116

As = .0116 X 6.5 X 12 X 5.5 = 5 sq in

Use #8 bars at 1 ft spacing.

Bars are placed at these spacings in both directions and because of the short spans there is no bar cut-off. A summary of design results for other floor loadings is included in the costing section.

Costing. An initial cost for all floor loading was calculated in dollars per 1000 square feet. This capital cost was then converted to an annual cost over an assumed 25 year life. No maintenance costs were included. There was no salvage value for the floor.

Slab costs (no reinforcing)*:

10 inch @ $1.45/sq ft

11 inch @ $1.58/sq ft

12 inch @ $1.70/sq ft

* (Means, 1975:62)

Sealer: $0.015/sq ft (Means, 1975:59)

Reinforcement: $675/ton (Means, 1975:57)

Piles: $4.50/sq ft (McAndrews, 1976)

For the maximum calculated reinforcement of #5 bars @ 6 inches and #8 bars @ 1 ft in both directions this was calculated to an equivalent cost per 1000 sq ft.

(64 + 64) X .31/144 X 490/2000 X 675 X (32 + 32) X .79/144

X 490/2000 X 675 = $104 per 1000 sq ft

This cost has been assumed for all floors analyzed as the moments change only marginally for each case.

TABLE C-10-1

COSTS OF PILE SUPPORTED FLOOR

Floor Load (psf)	2,000	3,000	4,000	6,000	8,000
Thickness (in)	10	11	11	12	10
Pile Spacing (ft)	6.5	5.5	4.5	4.0	3.0
Piles Per 1000 sq ft	23.67	33.06	49.38	62.50	111.11
Pile Cost $/1000 sq ft	5,326	7,439	11,110	14,063	25,000
Slab Cost $/1000 sq ft	1,450	1,580	1,580	1,700	1,450
Sealer Cost $/1000 sq ft	15	15	15	15	15
Reinforcement $/1000 sq ft	104	104	104	104	104
Total Cost $/1000 sq ft	6,895	9,138	12,809	15,882	26,569
Annual Cost $/1000 sq ft	760	1,007	1,411	1,750	2,927

Bridge Crane System Appendix Symbols

Af - Area of the compression flange

a_y - Component of amplification factor (for solving Modified Formula (1.6-1 a) when bending is about the y-y axis)

By - Bending factor with respect to the y-y axis (for determining the equivalent axial load in columns subjected to combined axial loading conditions)

Cb - Bending coefficient (dependent on moment gradient)

Cmy - Coefficient applied to bending term in interaction formula and dependent upon column curvature caused by applied moments about the y-y axis

d - Depth of beam

Fa - Axial stress (permitted in the absence of bending moment) (ksi)

Fb - Allowable bending stress about the y-y axis (in the absence of axial force)

Fby - Allowable bending stress about the y-y axis (in the absence of axial force)

Fy - (specified minimum) yield stress (of the type of steel being used)

M - Moment

My - Moment about the y-y axis

K - Effective length factor

Lb - Unbraced length of the compression flange

Lc - Maximum unbraced length of the compression flange at which

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the allowable bending stress may be taken at 0.66 Fy

l - Distance between cross-sections braced against twist or lateral displacement of the compression flange

P - Axial load

$P+P'$ - Sum of applied load and equivalent axial load due to bending component in members subject to axial and bending loads

r_T - Radius of gyration of a section comprising the compression flange plus one-third of the compression web area, taken about an axis in the plane of the web bending

ry - Lesser radius of gyration

S - Section modulus

w - Weight due to a uniform load

APPENDIX C-11

BRIDGE CRANE SYSTEM

Load Determination. Prior to the analysis of the crane frame, an accurate determination of loads to be accommodated was made. As was mentioned in the discussion of the bridge crane system, the bridge crane loads were based on manufacturer's data (Otis, 1975:22). The maximum wheel load multiplied by the 15 percent impact allowance is 53.65 kips (1.15 X 46.65 kips). Lateral loading was calculated using the recommended value of five percent of gross weight.

Net crane weight = 88.42 kips

Maximum load = 120.00 kips

Gross weight = 208.42 kips

Lateral force = .05 X 208.42 = 10.42 kips

It was assumed the lateral force would be equally distributed over each of the two crane frames. The uniform load used in the analysis was made up of the weight of the crane rail and beam.

For the design wheel loads, A.S.C.E. 175 pounds per yard rail was used (AISC, 1973:1-137). An assumed weight of 200 pounds per foot was used for the initial beam. Combining the weight of the crane rail and beam results in a uniform load of .0215 kips.

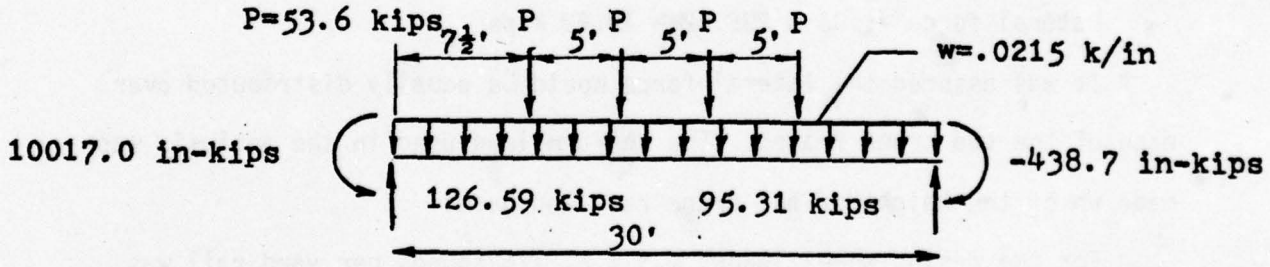
200 lb/ft + 175 lb per yd/3 ft per yd = 258.33 lb/ft

258.33 lb per ft/(12 in per ft X 1000 lb per ft) = .0215 k/ft

Load Application. Loads were applied to provide maximum stresses in the individual members in the frame. The influence lines for shear and moment at a support and moment at the center of a continuous span

served as a qualitative basis for load placement for beam flexural design (Wang, 1973:246). The loading situations for maximum positive and negative moment are shown in Figure C-11-1. The critical loading situations for a column cannot be directly determined since the column stress is affected by axial load and bending moment. The bending moment taken by the column is dependent upon the relative stiffness of the members forming a joint, as well as, the actual angular rotation of the joint. The case for the largest column axial force occurred when a beam was loaded as shown in Figure C-11-2. The maximum moment in a column occurred during the loading situation illustrated in Figure C-11-1.

Beam Design. The following free body diagram shows the forces applied to the beam section for a 30 foot column spacing.

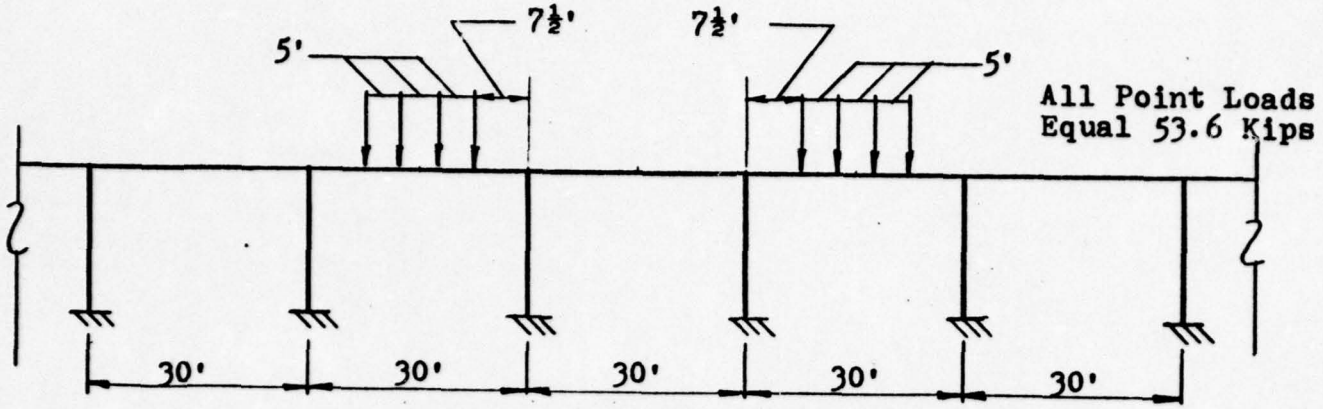


These forces were obtained from the STRESS output for the loading condition in Figure C-11-1. Since the largest allowable stress is 0.66 Fy for a compact section with Lc > Lb (AISC, 1973:5-66), an approximate value of the required section modulus can be obtained for A36 steel.

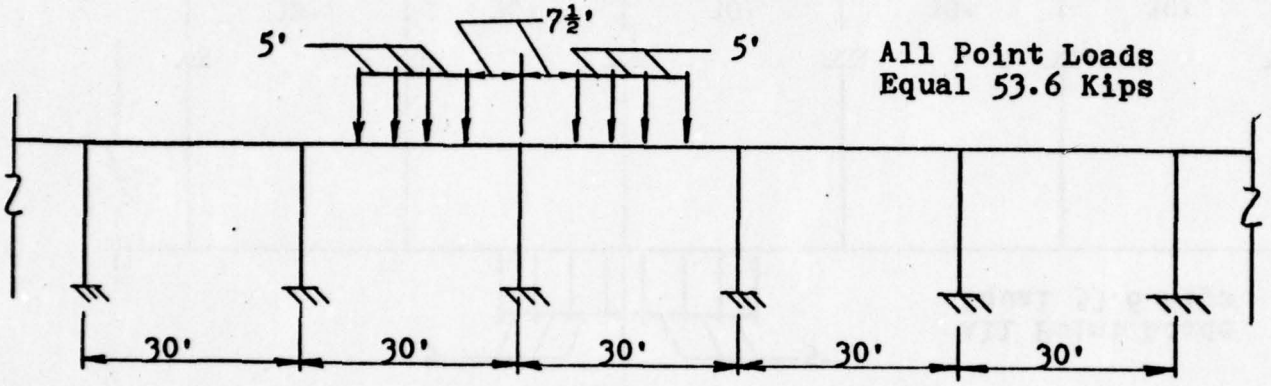
$$S = M/0.66\ Fy \qquad \text{(C-11-1)}$$

$$S = 10{,}017/(0.66 \times 36) = 417.38\ in^3$$

To meet the required section modulus criteria, a W27 X 177 was used.



Wheel Placement For Maximum
Positive Moment



Wheel Placement For Maximum
Negative Moment

FIGURE C-11-1 WHEEL PLACEMENT FOR MAXIMUM POSITIVE AND NEGATIVE MOMENT

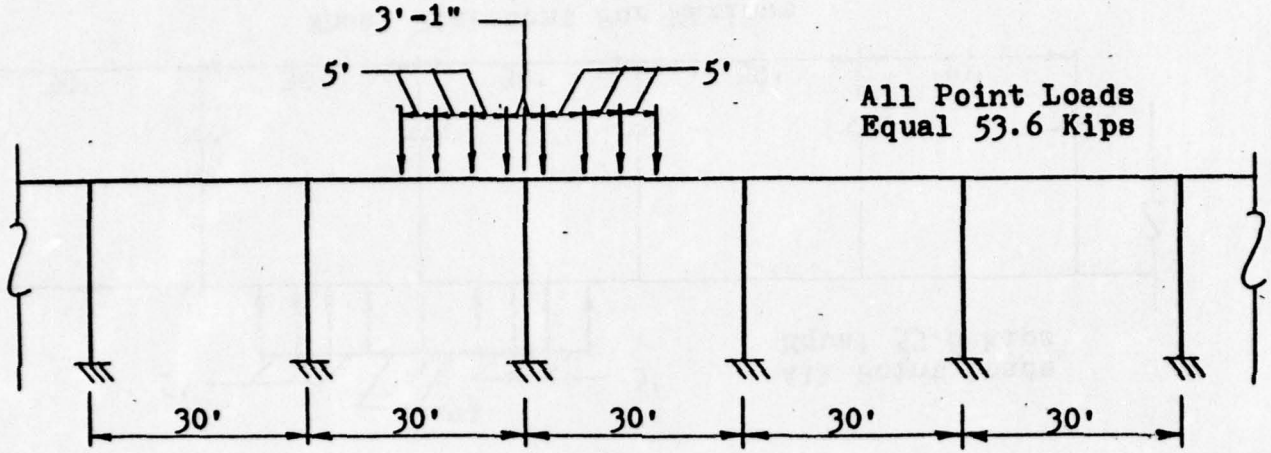


FIGURE C-11-2 WHEEL PLACEMENT FOR MAX COLUMN STRESS

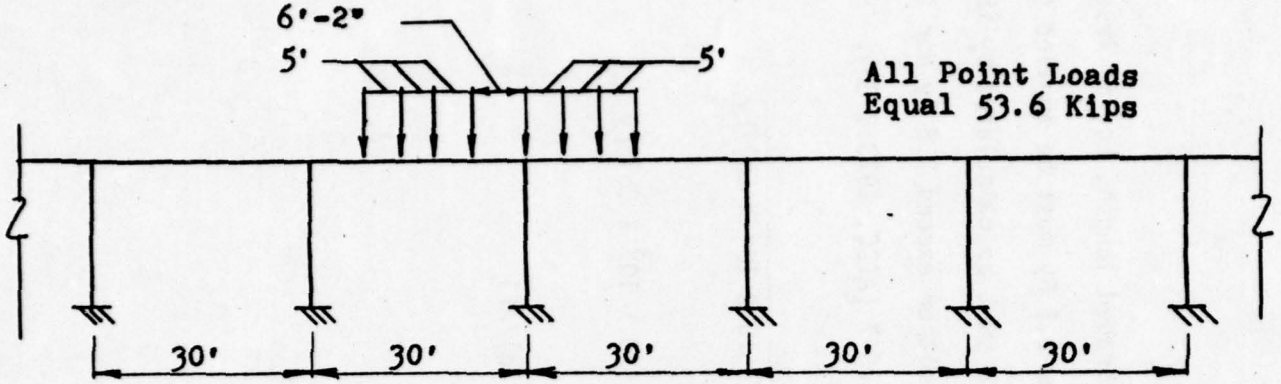


FIGURE C-11-3 WHEEL PLACEMENT FOR MAX BEAM SHEAR

Selected section properties are listed below (AISC, 1973:2-32).

r_T = 3.77

S = 494

Lc = 14.9

Lu = 28.4

d/Af = 1.63

Since the limiting value for unbraced length, Lu, is less than Lb, a reduction in allowable stress below 0.6 Fy must be applied (AISC, 1973: 2-3). When Lb is greater than Lu, Fb must be calculated by the provisions of AISC Section 1.5.1.4.6a and may neither exceed 0.6 Fy nor the larger value given by Formulas 1.5-6a and 1.5-7 (AISC, 1973:2-85). Formulas 1.5-6a and 1.5-7 apply when

$$\sqrt{(102 \times 10^3 \times Cb)/Fy} < l/r_T < \sqrt{(510 \times 10^3 \times Cb)/Fy} \qquad \text{(C-11-2)}$$

Formula 1.5-6a

$$Fb = \{2/3 - (Fy(l/r_T)^2)/(1530 \times 10^3 \times Cb)\}Fy \qquad \text{(C-11-3)}$$

Formula 1.5-7

$$Fb = (12 \times 10^3 \times Cb)/\{(l \times d)/Af\} \qquad \text{(C-11-4)}$$

Using (C-11-2)

$$53.22 < 95.49 < 119.02$$

From (C-11-3)

Fb = 16.28 ksi

From (C-11-4)

Fb = 20.45 ksi

Since 0.6 X 36 > 20.45 > 16.28

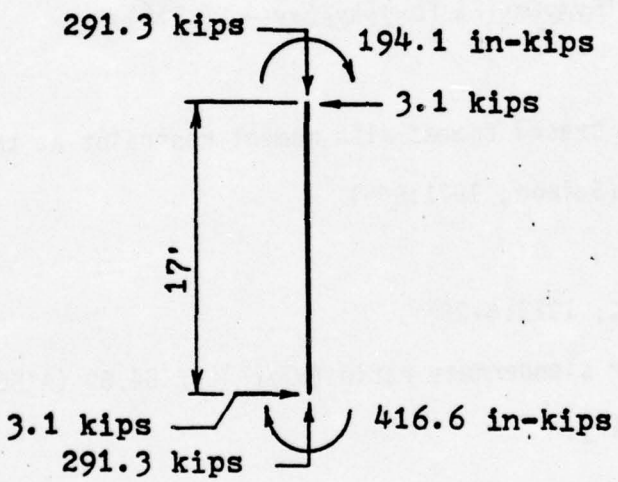
Fb allowable = 20.45 ksi

Fb actual = 10,017/494 = 20.28 ksi

Therefore a W27 X 177 section is satisfactory for flexural stress.

The allowable shear for this section is 287 kips (AISC, 1973:2-32). The maximum shear from Figure C-11-3 is 177.1 kips. Since the allowable is greater than the maximum possible, the shear criteria is satisfied.

Column Design. The following set of calculations illustrates the procedure used in the design and analysis of the crane frame columns. Depicted below is the free body diagram of a column under the critical loading situation. The applied forces were taken from STRESS output.



For a 30 foot column spacing situation, a W14 X 111 member was required to satisfy AISC requirements for axial compression and bending about the weak axis. The column length of 17 feet was necessary to provide adequate vertical clearance between the bridge crane and the rail cars. Listed below are member properties used in the analysis (AISC, 1973: 3-15).

W14 X 111

By = .526

$a_y = 68 \times 10^6$

$r_y = 3.73$

The AISC approach for combined bending and axial loading converts the forces into an equivalent axial load. This axial load is then compared to the theoretical allowable axial load based on the Column Research Council theory of column behavior. By using AISC Modified Formula 1.6-1a, the equivalent axial load is determined (AISC, 1973:3-9). Modified Formula 1.6-1a is listed below.

$$P + Py' = P + \{ByMyCmy(Fa/Fby)(ay/(ay - P(Kl)^2)\} \qquad \text{(C-11-5)}$$

where:

Cmy = 0.85 for braced frames with moment restraint at the end of members (Salmon, 1971:645)

My = 416.6

K = 1.0 (AISC, 1973:5-25)

Fa = 17.90 for slenderness ratio (Kl/r_y) of 54.69 (AISC, 1973: 3-15, 5-17)

P = 291.3

Using Equation (C-11-5), the equivalent axial load, P + Py', is 475.7 kips. The maximum allowable axial load for a W14 X 111 column, with an effective length of 17 feet, is 576 kips (AISC, 1973:3-15). An intentional safety factor is included to account for the possibility the boundary conditions for the braced frame may not be completely satisfied during field construction.

Economic Analysis. The following calculations illustrate the method used to arrive at the initial cost of the dual line bridge crane system.

No annual cost for operations and maintenance has been included. The initial cost spread over a 25 year life cycle is also computed.

A summary of the structural steel required for a crane frame with a 30 foot column spacing is listed below.

Structural Steel

Description	Number	Weight (Lbs)
Columns - W14X111	32 (17 foot each)	60,384
Bracing - W14X111	4 (24 foot each)	10,656
Beams - W27X127	900 feet	159,300
	Total	230,340

Structural steel cost figures are based on 1976 Means prices. For the specific structural steel required, the cost is $880.00 per ton delivered to the Washington, D.C. area. It was assumed this price would be representative of delivered costs at Norfolk, Virginia. Using this information, the cost of structural steel was as follows:

230,340 lbs X 1 ton/2000 lbs X $880/ton = $101,350

The foundation cost consists of the incremental cost associated with using the train shed and general storage area foundations. The foundation design (see "Foundations and Floor" section) showed one 50 ton capacity pile would be required for each column footing. Based on NAVFAC pricing information (McAndrews, 1976) of $225 per 50 ton pile, this cost was:

32 piles X $225/pile = $7200

Crane track pricing information came from manufacturer's data (Harnishfeger, 1976). The cost calculations are as follows:

900 ft X(1 yd/3 ft) X 175 lb/yd X $.30/lb = $15,750

The incremental length of train track associated with the dual system

was assumed to be 600 feet. Using Means prices (Means, 1975: 44), the cost figures are as follows:

600 ft X $37.25/ft = $22,350

The final component of the system is the bridge crane itself. The cost of two 60 ton, 70 foot bridge cranes is $490,000 (Harnishfeger, 1976).

Summation of the cost of individual system components results in an overall cost of $636,649. Using a 25 year life cycle, this is equivalent to an annual cost of $70,139.62.

Secure Storage Appendix Symbols

A - Cross sectional area (in^2)

A_G - Gross area of concrete (in^2)

Fa - Computed axial stress (ksi)

l - Span length (in)

P - Axial load (kip)

r - Radius of gyration (in)

w - Uniform load per foot

APPENDIX C-12

SECURE STORAGE

The criteria for the secure storage area provided by EATG did not specify the degree of security required. It was stated that small arms would be stored in the area. To provide a maximum of flexibility GCE-76S upgraded the storage classification to secret. As weapon systems are developed more modular sub-assemblies contain classified components. Future storage requirements will be for larger sub-assemblies as the remove and replace field maintenance concept is expanded.

Roof Slab. Light weight concrete was selected to reduce the dead load on the supporting structure and foundations. An eight inch thick reinforced roof column spacing was reduced to 30 feet by 30 feet because there was no vehicular traffic in the vault.

Four roofing schemes were investigated; poured in place two-way slab with beams, girders, and columns; one-way slab on steel framing; precast roof sections on steel framing; and poured in place slab on steel decking supported by steel framing.

A major expense of the one-way and two-way slabs would be the forming that would only be used once and have to be installed at a height of 35 feet. The roof of the vault would be in the same plane as the roof of the 30 foot structure. It must be remembered that the 30 foot structure is actually 36 feet from floor to roof and the 30 feet denotes the clear span between the floor and the bottom chord of the main frame.

A cursory investigation of the cost of forming the one and two-way

slabs exceed the cost of supporting the slab on a steel decked frame. Therefore, the roof slab was designed as a uniform load applied to a joist and beam frame. The load assumptions were as follows:

Snow	20.0 psf (AFM 88-3, 1966)
Roof	10.0 psf (Appendix C-4)
Ducts and Piping	2.0 psf
Light Weight Concrete	95.0 pcf (Wang, 1973:7)

Live plus dead load = 95 psf + joist

Joist selected from AISC tables = 30 H 11

580 plf/95 psf = 6.1 foot joist spacing

Point load on beam due to joist weight

(95 psf)(6 ft)(30 ft) + (18.8 plf)(30 ft) = 17.66 kips

Cost of forms and scaffolding at 35 foot height (Means, 1974:242)

Forms = $276.00 per 100 sq ft

$ 25.00 per 100 sq ft for heights of 20 to 35 feet

Total $301.00 per 100 sq ft = $3.01/sq ft

Steel decking and joist (Means, 1975:286)

20 gauge steel decking = $0.90/sq ft

30 H 11 joist 6 foot spacing

(18.8 plf)(6 ft)($0.46/lb)/(30 ft)(6 ft) = $1.44/sq ft

Total $2.34/sq ft

The steel decking and joist is less expensive than the form work.

Selection of Steel Members. The beam point load per joist was:

(95 psf)(6 ft)(30 ft) + (18.8 plf)(30 ft) = 17.66 kips

The beam was assumed to be pin connected at the column supports and have

a maximum mid-span moment of 0.125 wl^2. The 0.125 wl^2 moment was a conservative figure for the maximum moment in a continuous beam with seven supports. The assumed loading is shown in Figure C-12-1.

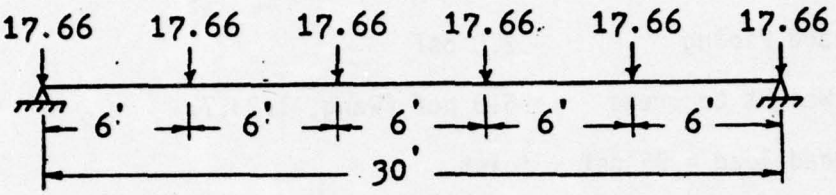


FIGURE C-12-1 ASSUMED CONTINUOUS BEAM LOADING

Conversion of point loads to uniform load (AISC, 1973:2-26).

(4.80)(17.66 kips) = 84.77 kips per ft

assumed AISC deflection coefficient = 1.01

Beam depth was not a problem so a 24 inch wide flange was proposed. A W24X76 was selected from the Fy 36 ksi beam tables capable of supporting a 94.0 kip load with a span length of 30 feet. Deflection from the table was 0.93 inches.

Concentrated deflection = (1.01)(0.93 in)(84.77)/94 = 0.847 in

0.847 < 0.93 in

The load per column was:

(5)(17.66 kips) + (30 ft)(0.076 kips/ft) = 90.58 kips

Try W12X53 to match the other interior columns

K = 0.75

Kl = (0.75)(33.33 ft) = 25 ft

From the AISC Fy = 36 ksi column tables using an effective length of 25 ft

W12X53 allowable axial load = 158 kips

W12X50 allowable axial load = 94.5 kips

Select the W12X50 column

Foundations. The foundations were proportioned from those designed to support the main structure (Appendix C-5). Foundations to support an axial column load of 140 kips were 12 ft by 12 ft by 1.5 ft thick with a 2 ft by 2 ft by 2 ft high pedestal. The bearing area of that foundation was 144 sq ft.

Vault column foundation

(90.58/140)(144 sq ft) = 93.17 sq ft = $(9.65 \text{ ft})^2$

Use a footing 9.75 ft by 9.75 ft by 1.5 ft thick

Cost Estimate. All cost estimates were developed using the Means Cost Data, 1976.

Light weight concrete

LW Concrete	\$31.80/cu yd
Labor	\$10.15/cu yd
Pumping to Roof	\$ 2.75/cu yd
Total	\$44.70/cu yd

Roof slab volume

(180 ft)(180 ft)(0.67 ft)/27 = 800 cu yd

Cost of light weight concrete in place

(800 cu yd)(\$44.70/cu yd) = \$35,760

Temperature steel

Minimum steel area = $0.0014 A_G$

Minimum steel = (0.0014)(0.67 ft)(180 ft) = 0.168 sq ft = 25.2 in^2

Maximum spacing = 1.5 ft, therefore, 121 bars are required

24.2 in^2/121 bars = 0.10 in^2/bar, therefore, use #4 bars

Reinforcing bars

(121 bars/set)(2 sets)(180 ft/bar)(0.668 lb/ft)($0.44/lb = $12,803

Steel structure

20 gauge steel roof decking

(180 ft)(180 ft)($0.90/sq ft) = $29,160

Columns W12X50

(49 ea)(33.33 ft ea)(50 lb/ft)($0.44/lb) = $35,930

Joist 30 H 11

(222 ea)(30 ft ea)(18.8 lb/ft)($0.46/lb) = $57,596

Beam W24X76

(7 ea)(180 ft ea)(76 lb/ft)($0.44/lb) = $42,135

Foundation 9.75 by 9.75 by 1.5 ft

(49 ea)(5.6 cu yd ea)($72/cu yd) = $19,757

Vault doors

Standard size 40 in by 78 in = $ 2,605

Special manufacture 8 ft by 8 ft

Standard door has 21.66 sq ft at $1,605 = $120/sq ft

Assume special manufacture at $200/sq ft

(64 sq ft)($200/sq ft) = $12,600

Walls

(2 ea)(180 lf ea)(36 ft high)($4.63/sq ft) = $60,005

APPENDIX E-1

INFLATED ENERGY COST CALCULATIONS

It is imperative to use an accurate energy cost in determining the life cycle cost of the internal energy system. In order to estimate an accurate energy cost, it is necessary to assume that the cost of energy will inflate during the life of the facility; therefore, some method to account for this inflation should be considered (York, 1975b:3). For this study, an energy inflation rate of ten percent for ten years was used as a conservative assumption for electrical energy inflation (Yerian, 1976) (Castin, 1976)(York, 1975b:3). An inflation rate of six percent for ten years was used for fuel oil (Castin, 1976). This appendix presents the inflated energy costs for electrical power and #2 diesel oil in terms of an annual cost. A sample calculation showing how the annual cost for #2 diesel oil was determined is also presented. Figure E-1-1 shows the economic model used for the sample calculation.

Base rate of #2 diesel oil = $0.33 per gal (Eitel, 1976)

Interest rate = 10%

Inflate at 6% for 10 years.

Escalation factor = 1.34 (York, 1975b:9)

Average annual cost for first 10 years:

AC = 1.34 X 0.33 = $0.4422

Present worth for first ten years:

(P/A, 10%, 10) = 6.144 (Grant, 1970:610)

P(1) = 0.4422 X 6.144 = $2.7169

Annual cost for 10 to 25 years:

$AC = \$0.33 \times (1.06)^{10} = \$0.5910$

Present worth at 10th year:

(P/A, 10%, 15) = 7.606 (Grant, 1970:610)

$P(2) = 0.5910 \times 7.606 = \$4.495$

Present worth at year zero:

(P/F, 10%, 10) = 0.3855 (Grant, 1970:610)

$4.495 \times 0.3855 = 1.733$

$P = 1.733 + 2.7167 = 4.4497$

Annual cost of #2 diesel oil:

(A/P, 10%, 25) = 0.11017 (Grant, 1970:610)

$4.4497 \times 0.11017 =$ $0.49 per gal

The inflated annual cost of #2 diesel oil used for this study is $0.49 per gallon.

The inflated annual electrical cost was calculated in a similar manner. The base rate of electricity for the Norfolk area is $0.021 per kilowatt-hour based on information from Langley AFB (Russell, 1976). The inflated annual electrical cost used for the study is $0.0441 per kilowatt-hour.

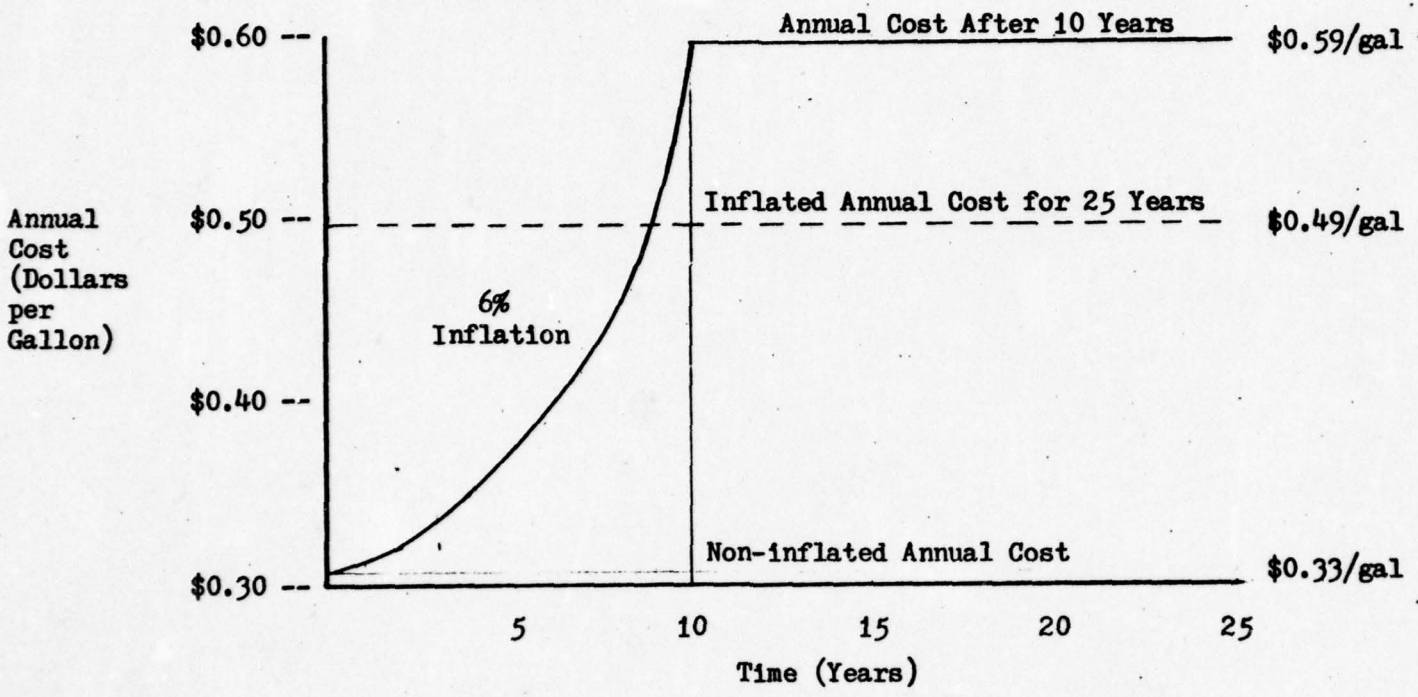


FIGURE E-1-1 ECONOMIC MODEL FOR INFLATED FUEL OIL COSTS

Material Handling Equipment Appendix Symbols

A - Area of a 10 aisle stacker crane system

BA - Bin area

c - Clear space above containers

COL - Column width

CW - Container width

d - Container depth

ft - Feet

H - Ceiling height

h - Container height

HP - Horsepower

HPR - System horsepower requirement

in - Inch

L - Length of aisle

min - Minute

NBIN - Number of bin openings

NBL - Number of bin lines

NGSL - Number of general storage lines

NH - Number of containers in a vertical section

NL - Number of containers in a horizontal section

NLINE - Number of warehouse lines

NOPEN - Number of openings per aisle

NR - Number of 10 aisle systems required

NRL - Number of rack lines

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RA - Rack area

W - Width of work area

WD - Width of a 10 aisle system

APPENDIX E-2

MATERIAL HANDLING EQUIPMENT CALCULATIONS

This appendix includes sample calculations used to develop the level of technology projected for the 30 foot warehouse module. These calculations represent only a "best guess" of "typical" material handling systems and do not constitute a study of the material handling aspects of the warehouse module. Items developed in this section include the conveyor loads for the receiving area, the bin and rack stacker crane loads for the mechanized area, and the battery charger loads for the general storage area. All calculations shown were either done by or based on information supplied by EATG (Vrba, 1976)(Mucci, 1976).

Receiving Area Conveyor Loads.

Given:

Twenty - 30 inch conveyor lines at 50 ft

20 diverters

8 input lines

8 output lines

Ten - 48 inch conveyor lines at 40 ft

10 diverters

4 input lines

4 output lines

Horsepower required:

30 inch conveyors

20 lines @ 0.75 HP/LINE = 15 HP

20 diverters @ .75 HP/Unit = 15 HP

8 input lines @ .75 HP/LINE = 6 HP

8 output lines @ .75 HP/LINE = 6 HP

48 inch conveyors

10 lines @ 1.5 HP/LINE = 15 HP

10 diverters @ 1.5 HP/Unit = 15 HP

4 input lines @ 1.5 HP/LINE = 6 HP

4 output lines @ 1.5 HP/LINE = 6 HP

Miscellaneous

Receiving area conveyor horsepower = 100 HP

Similar calculations were used to project the conveyor requirements for packing, set assembly, shipping, and other operating area sections.

Mechanized Area Bin and Rack Stacker Crane Loads. Mechanized area loads were developed for bin and rack stacker crane systems to model a highly mechanized automated storage facility. Assumed "typical" operating characteristics and storage requirements are listed below.

Bin area = 1.82 acres = 79,279 sq ft

Rack area = 4.94 acres = 215,186 sq ft

Support area = 3.64 acres = 158,558 sq ft

Mechanized area = 10.4 acres = 453,024 sq ft

Bin size = 24 in X 18 in X 9 in

Rack pallet size = 40 in X 48 in X 42 in

Horizontal crane speed = 600 ft/min

Vertical crane speed = 150 ft/min

Bin crane horsepower = 10 HP

Rack crane horsepower = 20 HP

Bin to ceiling clearance = 18 in

Rack to ceiling clearance = 18 in

Bin horizontal support thickness = 1.25 in

Rack horizontal support thickness = 4 in

Bin clear space above container = 0.5 in

Rack clear space above pallet = 2 in

Ceiling height = 30 ft

Aisle length = 120 ft

Bin aisle work area width = 64 in

Rack aisle work area width = 120 in

Bin vertical support width = 1.875 in

Rack vertical support width = 3 in

Bin horsepower requirements:

Number of containers in a vertical section.

NH = H - 18/ (h + c + 0.25) = (30 ft X 12 in/ft - 18 in)/
(9 in + 0.5 in + 0.25 in) = 35

Number of containers in a horizontal section.

NL = (L - W)/(CW + COL) = 120 ft X 12 in/ft - 64 in)/(18 in +
1.875 in) = 69

Number of opening per aisle.

NOPEN = 2 X NH X NL = 2 X 35 X 69 = 4830

Width of a 10 aisle system.

WD = (3 X d + 10.25) X 10 = (3 X 24 in + 10.25 in) X 10 X ft/12 in
= 68 ft

Area of a 10 aisle system.

A = L X WD = 120 ft X 68 ft = 8160 sq ft

Number of 10 aisle bin systems required.

NR = BA/A = 79,279 sq ft/8160 sq ft = 9.72 Use 10

Bin crane horsepower required.

HPR = 10 X NR X 10 = 10 HP X 10 systems X 10 cranes/system

= 1000 HP

Rack horsepower requirements:

Number of pallets in a vertical section.

NH = (H - 18)/(h + c + 2) = (30 ft X 12 in/ft - 18 in)/(40 in + 4 in + 2 in) = 7

Number of containers in a horizontal section.

NL = (L - W)/(CW + COL) = (120 ft X 12 in/ft - 120 in)/(40 in + 3 in) = 30

Number of openings per aisle.

NOPEN = 2 X NH X NL = 2 X 7 X 30 = 420

Width of 10 aisle system.

WD = (3 X d + 18) X 10 = (3 X 48 in + 18 in) X 10 X ft/12 in

= 135 ft

Area of a 10 aisle system.

A = L X WD = 120 ft X 135 ft = 16,200 sq ft

Number of 10 aisle rack systems required.

NR = BA/A = 215,186 sq ft/16,200 sq ft = 13.28 Use 13

Rack crane horsepower required.

HPR = 20 X NR X 10 = 20 HP X 13 systems X 10 cranes/system

= 2600 HP

Similar calculations were made for the 40 foot, 50 foot, and 60 foot buildings. Table E-2-1 shows the results.

TABLE E-2-1

MECHANIZED AREA STACKER CRANE REQUIREMENTS

HEIGHT (FT)	NO. OF BIN CRANES	BIN OPENINGS	BIN CRANE HP	NO. OF RACK CRANES	RACK OPENINGS	RACK CRANE HP
30	100	483,000	1000	130	54,600	2,600
40	70	618,239	700	100	73,800	2,000
50	60	814,200	600	80	97,920	1,600
60	50	945,300	500	65	112,840	1,300

General Storage Area Battery Charger Loads. The primary electrical load for the general storage area is the battery charging required to support the fork lifts. This load was extrapolated from information provided by EATG (Vrba, 1976)(Mucci, 1976). Load values were derived by computing the number of warehouse lines by factoring the projected number of bin lines. This information was then compared to AFLC records which showed the number of warehousemen and fork lifts necessary for a given number of lines. Then, using a known value for the battery charging horsepower requirements for a given number of fork lifts, the general storage area horsepower requirements were computed by direct proportion. Calculations for the 30 foot building are shown below.

Given:

1,098,000 lines require 549 warehousemen

549 warehousemen require 173 fork lifts

100 fork lifts require 500 HP battery charging

Battery charging horsepower requirements:

From mechanized area calculations the number of bin openings is

NBIN = 483,000 openings

Assuming 3.33 lines per bin opening then

NBL = 1,608,390 lines

Assuming the number of bin lines equals 70 percent of total warehouse, then the number of warehouse lines equals:

NLINE = NBIN/0.70 = 2,297,700 lines

Assuming one line for each rack opening, then the number of general storage lines equals:

NGSL = NLINE - NBIN - NRACK = 2,297,700 - 1,608,390 - 54,600
= 634,710

By direct proportion the number of warehousemen required is

NWR = 549/1,098,000 X NGSL = 549 people/ 1,098,000 lines X 634,710 lines = 317 people

Again by direct proportion the number of fork lifts required equals:

NFLR = 173/549 X NWR = 173 fork lifts/549 people X 317 people
= 100 fork lifts

And the battery charging horsepower equals

HP = 500/100 X NFLR = 500 HP/100 fork lifts X 100 fork lifts
= 500 HP

Similar calculations were done for the 40, 50, and 60 foot buildings. The results are shown in Table E-2-2.

TABLE E-2-2

GENERAL STORAGE AREA HORSEPOWER REQUIREMENTS

HEIGHT (FT)	NO. OF BULK LINES	NO. OF WAREHOUSEMEN	NO. OF FORK LIFTS	BATTERY CHARGING HP
30	634,710	317	100	500
40	808,515	404	127	637
50	1,064,060	532	168	839
60	1,236,239	618	195	975

APPENDIX E-3

Coefficient Of Utilization Appendix Symbols

RCR - Room cavity ratio

h - Height of room cavity

L - Length of room cavity

W - Width of room cavity

CCR - Ceiling cavity ratio

hc - Height of ceiling cavity

p_c - Basic ceiling reflectance value

p_w - Wall reflectance value

p_{cc} - Effective ceiling reflectance value

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APPENDIX E-3

CALCULATION OF COEFFICIENT OF UTILIZATION

FOR THE LIGHTING DESIGN

This appendix shows a sample calculation of how the coefficient of utilization was obtained for the 30 foot high general storage area of the facility. The coefficients of utilization for other areas in the facility were calculated in a similar manner and are shown in Table E-3-1.

The depth of the floor cavity = 2.5 ft

The depth of the room cavity = 27.5 ft

The depth of the ceiling cavity = 5 ft

The room cavity length = 110 ft

The room cavity width = 110 ft

The basic ceiling reflectance value = 0.80

The wall reflectance value = 0.50

The floor reflectance value = 0.20

Determine the room cavity ratio (RCR):

$$RCR = 5\ h\ (L + W)/L \times W = 5(27.5)(110 + 110)/110 \times 110 = 2.5$$

Determine the ceiling cavity ratio (CCR):

$$CCR = 5\ hc\ (L + W)/L \times W = 5(5)(110 + 110)/110 \times 110 = 0.45$$

Determine the effective ceiling reflectance:

From chart (I.E.S., 1972:9.10)

With input of:

$p_c = 0.80$

$p_w = 0.50$

The effective ceiling reflectance = 0.73

Determine the coefficient of utilization:

From General Electric photometric data for the Duraglow luminaire with a 400 watt Lucalux lamp. (G.E., 1973b:35-174985)

With input of:

p_{cc} = 0.73

p_w = 0.50

RCR = 4.50

The coefficient of utilization = 0.800

TABLE E-3-1

COEFFICIENTS OF UTILIZATION FOR THE VARIOUS LIGHTING ZONES

AREA	COEFFICIENT OF UTILIZATION *
Operating Area	0.800
30 Ft General Storage And Mechanized Area	0.800
40 Ft General Storage And Mechanized Area	0.741
50 Ft General Storage And Mechanized Area	0.692
60 Ft General Storage And Mechanized Area	0.577 **
Cooler	0.767 ***
Freezer	0.767 ***
Vestibule	0.472

* Based on Duraglow luminaire with 400 watt Lucalux lamp.

** Based on Duraglow luminaire with 1000 watt Lucalux lamp.

*** Based on Duraglow luminaire with 250 watt Lucalux lamp.

APPENDIX E-4

CIRCUIT COST CALCULATIONS FOR THE LIGHTING DESIGN

The purpose of this appendix is to show how the lighting circuit costs were developed. A sample calculation for the circuit cost of the 30 foot mechanized and general storage area is presented in detail. A busway circuit was used for the design. The circuit costs for the other areas in the facility are presented in Table E-4-1.

Before developing a circuit cost, it was necessary to develop a lighting circuit arrangement. First, the number of luminaires per circuit was determined. Next, the spacing between luminaires was determined. Then a circuit layout for each area was assumed in order to estimate the length of wire run. It is important to point out that the circuit layout is affected by the layout of the bins and racks within the area. Since this information was not provided, it was assumed that the luminaires would be spaced evenly throughout the area. Figure E-4-1 shows the circuit layout used for the cost calculations.

The cost of the circuit includes the cost of the circuit breaker panel plus the cost of wire and conduit from the circuit breaker panel to the busway circuit. The busway circuit cost includes the cost of the busway itself, the cost of the strength beams required to support the luminaires, the cost of a beam roller that allows the luminaire to move along the busway, and a lead-in-head that provides easy installation. Also included in the busway costs are the cost of the center feed box where the lead in wire connects to the busway circuit, the hooks required to hold the busway to the roof truss, and an installation cost.

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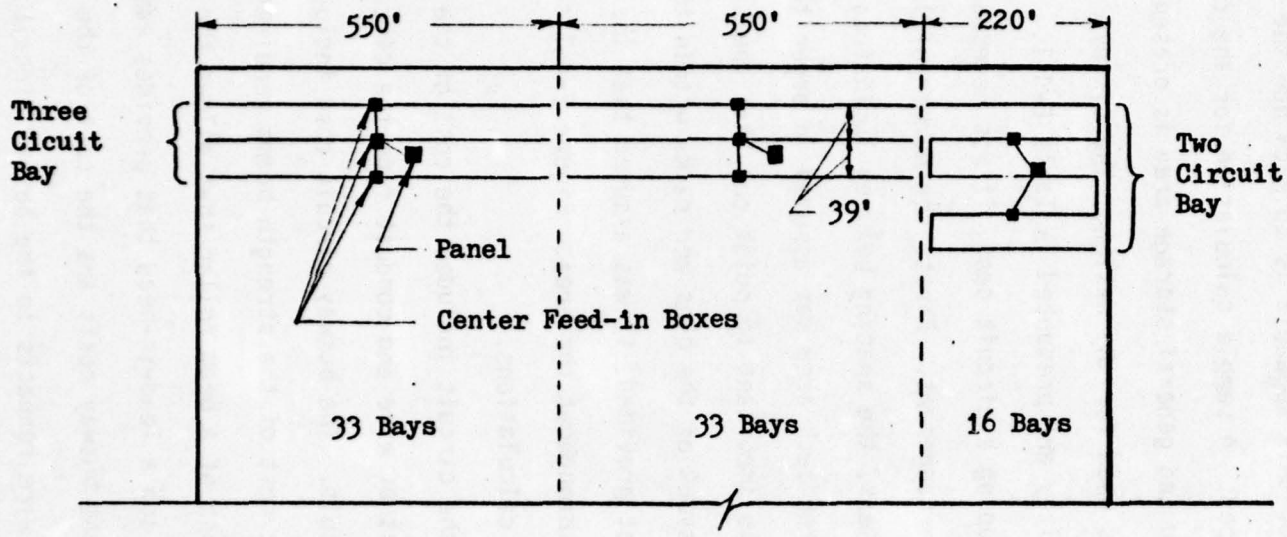


FIGURE E-4-1 CIRCUIT ARRANGEMENT FOR 30 FOOT MECHANIZED AND GENERAL STORAGE AREA

In order to develop the cost of wire and conduit, it was necessary to determine the wire size. The wire size is based on the amount of current the wire carries and the voltage drop. The circuit current was 24 amperes and the allowable voltage drop was three percent of the circuit voltage (NEC, 1974:70.32). The voltage drop in the circuit is the sum of the voltage drop in the busway portion of the circuit and the voltage drop in wire. To keep the voltage drop at minimum in the busway, a center feed box was used.

The following sample calculation shows how the circuit costs were developed for the 30 foot mechanized and general storage area. Circuit costs for other areas in the facility were developed in a similar manner and are summarized in Table E-4-1.

Determine the design length of busway:

Number of luminaires in the area = 1153

Number of circuits in the area = 84

Lights per circuit = 14

Spacing = $\sqrt{\text{Area/Number of lights}}$ = 39 ft

Design length per circuit = 14(39) = 550 ft

(Note busway comes in ten foot lengths)

Total design length = (550)(84) = 46,200 ft

Determine the voltage loss in the busway portion of the circuit: (using center feed box)

Voltage loss factor = 0.0009 (G.E., 1973:18)

Voltage loss = Length X Voltage loss factor X 0.05 X Current

Voltage loss in busway = 550/2(0.0009)(0.5)(20) = 2.48 volts or 0.90%

Determine the length of run for 3 circuit bay:

Length of run - panel to ceiling = 40 ft

Length of run - ceiling to farthest circuit in bay = 40 ft

Total length of run = 80 ft

Determine length of run for 2 circuit bay:

Length of run - wire to ceiling = 40 ft

Length of run - ceiling to farthest circuit in bay = 40 ft

Total length of run = 80 ft

Determine wire size:

Voltage drop factor = 5.817/24(0.8) = 0.3030

Try #8 copper wire (THW)

Maximum ampacity = 45 amps (NEC, 1974:70.131)

Consider the effect of the conduit on the maximum ampacity for 6 conductors in each conduit:

Reduction factor = 0.80 (Bussman, 1975:36)

Reduced ampacity = 0.80(45) = 31.5 (greater than 24 O.K.)

Voltage drop factor for #8 wire = 0.1504

This value is less than 0.3030, therefore O.K.

Use #8 copper wire.

This design is conservative. A #10 copper wire would meet the design requirements; however, if another wire were added to the conduit the reduced ampacity would be less than 24 amps. Since there would be a possibility of more than 6 wires in the conduit the #8 wire was selected.

Determine wire design lengths:

Total length of #8 wire for 3 circuit bays = 8844 ft

Total length of #8 wire for 2 circuit bays = 2560 ft

Total design length = 11,404 ft

Determine conduit sizes and design lengths:

3 bay panel to ceiling:

Use 1-1/4 in conduit (NEC, 1974:70.559)

Design length = 880 ft

2 bay panel to ceiling:

Use 1 in conduit (NEC, 1974:70.559

Design length = 320 ft

3 bay and 2 bay ceiling to busway:

Use 3/4 in conduit (NEC, 1974:70.559)

Design length = 2400 ft

Determine the busway costs: (G.E., 1975a:173)

Busway at $1.15 per foot:

Cost = 46,200(1.15) = $53,130.00

Strength bar at $0.69 per foot:

Cost = 46,200(0.69) = $31,878.00

Hangers at $0.41 per foot:

Cost = 46,200(0.41) = $18,942.00

Hooks at $0.75 each:

Cost = 1153(0.75) = $865.00

Lead-in-heads at $38.50 per circuit:

Cost = 84(38.50) = $3234.00

Center feed boxes at $8.00 per circuit:

Cost = 84(8.00) = $672.00

Installation at $1.00 per foot:

Cost = 46,200(1.00) = $46,200.00

Total cost = $154,921.00

Determine wire costs: (Means, 1975:218)

#8 copper wire at $0.23 per feet:

Cost = 11,404(0.23) = $2623.00

Determine conduit costs: (Means, 1975:215)

(Note: the costs are multiplied by a 1.25 factor to account for installation at increased heights)

1-1/4 in conduit at $1.55 per foot:

Cost = (1.25)(1.55)(880) = $1705.00

1 in conduit at $1.25 per foot:

Cost = (1.25)(1.25)(320) = $500.00

3/4 in conduit at $1.05 per foot:

Cost = (1.25)(1.05)(2400) = $3150.00

Total conduit cost = $5355.00

Determine panel cost: (G.E., 1975a:155)

Material and installation at $128.00 per circuit:

Cost = 84(128.00) = $10,752.00

TABLE E-4-1

BUSWAY CIRCUIT COSTS BY AREA

AREA	CIRCUIT COST
Operating Area	$1326
30 Ft Mechanized/General Storage Area	$2076
40 Ft Mechanized/General Storage Area	$2113
50 Ft Mechanized/General Storage Area	$2238
60 Ft Mechanized/General Storage Area	$1764
Freezer	$1122
Cooler	$1640
Vestibule	$2192

APPENDIX E-5

ECONOMIC COMPARISON OF HIGH INTENSITY DISCHARGE LIGHTING SYSTEMS

Three types of high intensity discharge (HID) lighting systems, high pressure sodium (HIDSOD), mercury vapor (MERC), and metal halide (METHAL), were compared to determine the most economical lighting system for the warehouse. This appendix outlines the method used to make the selection.

Two design cases are presented. Case 1 shows the economic comparison between HIDSOD, MERC, and METHAL for the operating area. The level of illumination used for the operating area was 50 foot-candles. Case 2 shows the economic comparison between HIDSOD, MERC, and METHAL for the 30 foot high general storage and mechanized areas. The level of illumination used for general storage and mechanized areas was 20 foot-candles (IES, 1972:9.81-9.91).

The Duraglow luminaire manufactured by General Electric Company was used for the study. A HIDSOD, MERC, or METHAL lamp can be used with the Duraglow luminaire. The coefficient of utilization and light loss factor for each lamp/luminaire combination was determined from manufacturer's data.

Lamp, luminaire, and accessory costs were obtained from manufacturers' catalogs. The catalog prices were multiplied by a 0.5 factor to reflect the savings achieved by making a large volume purchase (Geers, 1976). A circuit cost calculated specifically for the HIDSOD lighting system was used for all cases (see Appendix E-4). Although the circuit costs would change slightly for the MERC and METHAL lighting systems, it was assumed that the difference would not significantly affect the results of the economic comparison. A busway circuit was used in calculating the circuit

costs.

The following factors were considered when comparing the operations and maintenace costs:

1. Energy cost = $0.0441 per kilowatt-hour (see Appendix E-1)
2. Replacement ballast cost, each (G.E., 1974a)

   HIDSOD = $90.00

   MERC = $65.00

   METHAL = $70.00
3. Labor to replace one ballast = $15.00 (Geers, 1976)
4. Labor to clean one luminaire = $3.00 (Geers, 1976)

   Note: It was assumed that one fourth of the luminaires would be cleaned each year.
5. Spot relamping lamp cost, each (G.E., 1975b:22)

   HIDSOD = $24.00

   MERC = $6.20

   METHAL = $13.80

   Note: The catalog price was multiplied by a 0.4 factor to determine the relamping cost (Geers, 1976).
6. Labor to spot relamp, each = $3.00 (Geers, 1976)
7. Group relamping lamp cost, each (G.E., 1975b:22)

   MERC = $6.20
8. Labor to group relamp, each = $2.00 (Geers, 1976)

   Note: It is recommended that MERC lamps be replaced (group relamped) every three years.

The LGHTECON computer program was used to determine the number of

lamps required and the costs for the different lighting systems. The initial costs were converted to an annual cost using a ten percent interest rate and a zero salvage value after 25 years. The HIDSOD lighting system had the lowest annual cost of the three lighting systems considered and was the lighting system selected for the lighting design. Although this appendix only presents the comparison for a 30 foot mounting height in the general storage and mechanized areas, HIDSOD lamps were also the most economical system at the 40, 50, and 60 foot mounting heights.

Table E-5-1 shows the design input data for both Case 1 and Case 2, while Table E-5-2 shows the initial cost input data for Case 1 and Case 2. The design and cost results for Case 1 are shown in Table E-5-3, while Table C-5-4 shows the design and cost results for Case 2.

TABLE E-5-1

DESIGN INPUT DATA

ITEM	HIDSOD	MERC	METHAL
Watts Per Lamp	400	400	400
Initial Lamp Lumens	50,000	22,500	34,000
Initial Lamp Life (Hrs)	20,000	16,000	10,000
Watts Per Luminaire With Ballast	482	449	454
Coefficient Of Utilization	0.800	0.757	0.733
Ballast Life (Hrs)	100,000	100,000	100,000
Lamp Lumen Depreciation Factor	0.900	0.820	0.800
Lamp Dirt Depreciation Factor	0.840	0.840	0.840
Light Loss Factor	0.756	0.689	0.672

TABLE E-5-2

INITIAL COST INPUT DATA

ITEM	HIDSOD	MERC	METHAL
Luminaire Cost (Ea)	$ 104.00	$ 63.50	$ 74.00
Accessory Cost (Ea)	$ 7.60	$ 7.60	$ 7.60
Lamp Cost (Ea)	$ 30.00	$ 7.75	$ 17.25
Case 1 - Circuit Cost (Ea)	$1,326.00	$1,326.00	$1,326.00
Case 2 - Circuit Cost (Ea)	$2,067.00	$2,067.00	$2,067.00

TABLE E-5-3

DESIGN AND COST RESULTS FOR CASE 1 (OPERATING AREA)

ITEM	HIDSOD	MERC	METHAL
No. Of Luminaires	721	1,857	1,301
No. Of Circuits	53	126	89
Load In Kilowatts	347.5	833.8	590.7
Luminaire Cost	$ 74,984.00	$117,919.50	$ 96,274.00
Accessory Cost	$ 5,479.60	$ 14,113.20	$ 9,887.60
Lamp Cost	$ 21,630.00	$ 14,391.75	$ 22,442.25
Circuit Cost	$ 70,278.00	$167,076.00	$118,014.00
Annual Spot Relamping Cost	$ 4,858.96	$ 3,553.56	$ 10,910.91
Annual Group Relamping Cost	$ 0.00	$ 4,298.69	$ 0.00
Ballast Replacement Cost	$ 3,779.19	$ 7,416.12	$ 5,520.40
Cleaning Cost	$ 539.88	$ 1,738.15	$ 1,948.38
Energy Cost	$ 76,506.00	$183,557.20	$168,628.17
Total Annual Cost	$104,674.21	$235,102.06	$214,177.75

TABLE E-5-4

DESIGN AND COST RESULTS FOR CASE 2

(GENERAL STORAGE AND MECHANIZED AREAS)

ITEM	HIDSOD	MERC	METHAL
No. Of Luminaires	1,153	2,971	2,081
No. Of Circuits	84	201	143
Load In Kilowatts	555.7	1,334.0	944.8
Luminaire Cost	$119,912.00	$188,658.50	$153,994.00
Accessory Cost	$ 8,762.80	$ 22,579.60	$ 15,815.60
Lamp Cost	$ 34,590.00	$ 23,025.25	$ 35,897.25
Circuit Cost	$173,651.00	$415,467.00	$295,581.00
Annual Spot Relamping Cost	$ 7,770.30	$ 5,685.31	$ 17,452.43
Annual Group Relamp Cost	$ 0.00	$ 6,877.44	$ 0.00
Ballast Replacement Cost	$ 6,043.56	$ 11,864.99	$ 8,830.10
Cleaning Cost	$ 863.37	$ 2,780.56	$ 3,116.51
Energy Cost	$122,345.92	$293,671.75	$207,989.36
Total Annual Cost	$174,141.16	$392,460.84	$292,615.28

APPENDIX E-6

ECONOMIC COMPARISON OF BUSWAY VERSUS WIRE CIRCUITS

This appendix compares the cost of a busway circuit versus a wire circuit for the high pressure sodium lighting system selected for the facility. Two areas of the facility were compared. Case 1 compares the busway and wire circuit in the operating area of the facility, while Case 2 compares the two circuits in the 30 foot high mechanized and general storage area. Each circuit system is described, the cost input data is listed, and the final results of the comparison are presented.

Busway Circuit Description. The busway circuit is attached to a strength beam. The strength beam is necessary in order to strengthen the busway, thus providing adequate support for the luminaire. An adjustable strength beam roller hanger is attached to the roof purlins and the roller hanger supports the busway and strength beam assembly. The luminaire contains a hook, cord, and busway plug assembly which is attached to a heavy duty fixture hook on the busway (see Figure E-6-1). Rather than using an end feed, a center feed-in box is mounted at a busway joint near the center of the circuit in order to reduce the voltage drop in the busway. The circuit from the panel to the center feed-in box consists of wire in conduit.

The main advantages of the busway circuit system are its flexibility and ease of installation. In the event the configuration of the facility were to change, thus changing the lighting arrangement, the luminaire could be moved by simply moving the fixture hook along the busway. The busway roll-in technique of installation is an economical method of installing the luminaires, busway, and strength beam. The entire circuit can be

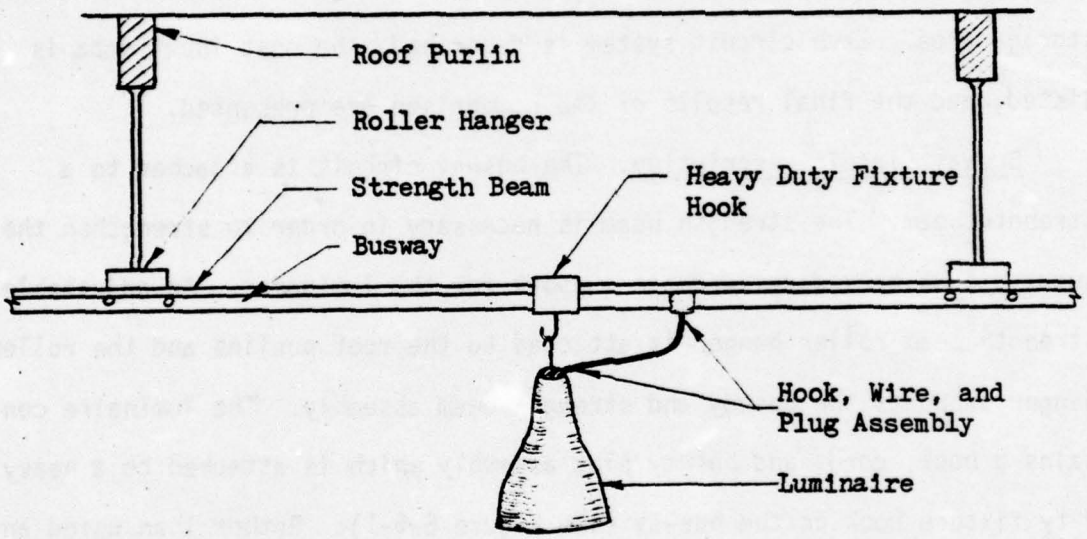


FIGURE E-6-1 BUSWAY CIRCUIT ASSEMBLY

installed from one central location. A lead-in head is attached to the first length of strength beam and started down the run. Each succeeding length of busway and strength beam is joined to the preceding length. The luminaire is plugged into the busway and hooked at the desired location and the entire assembly is pushed forward. Runs of up to 800 feet are not uncommon and can be installed from a central location (G.E., 1973a:22). Figure E-6-2 shows the roll-in method of installation.

Wire Circuit Description. The wire circuit consists of wire in conduit that runs from the panels to each luminaire outlet. The luminaire contains a hook, cord, and plug assembly which allows the luminaire to hook into loops that are mounted on the roof purlins. In some cases it may be necessary to run small channel members between the roof purlins to achieve proper luminaire spacing. For this study it was assumed that proper spacing could be obtained by attaching the loops to the roof purlins, thus the cost of the mounting bars was neglected. The wire and plug assembly runs to a circuit outlet. There is one outlet for each luminaire.

The main advantage of the wire circuit is that the cost of material is less than that for the busway circuit; however, the installation costs are high due to the high ceiling heights. Furthermore, the wire circuit is not as flexible as the busway circuit. If the lighting configuration were to change, the luminaire, the outlet, and the connecting loop must be moved in addition to rearranging the circuit wiring. This is far more expensive than simply sliding the luminaire along the busway. Because it is difficult to predict how often the lighting configuration in the facility will change, the cost of changing the configuration was not included in the economic analysis.

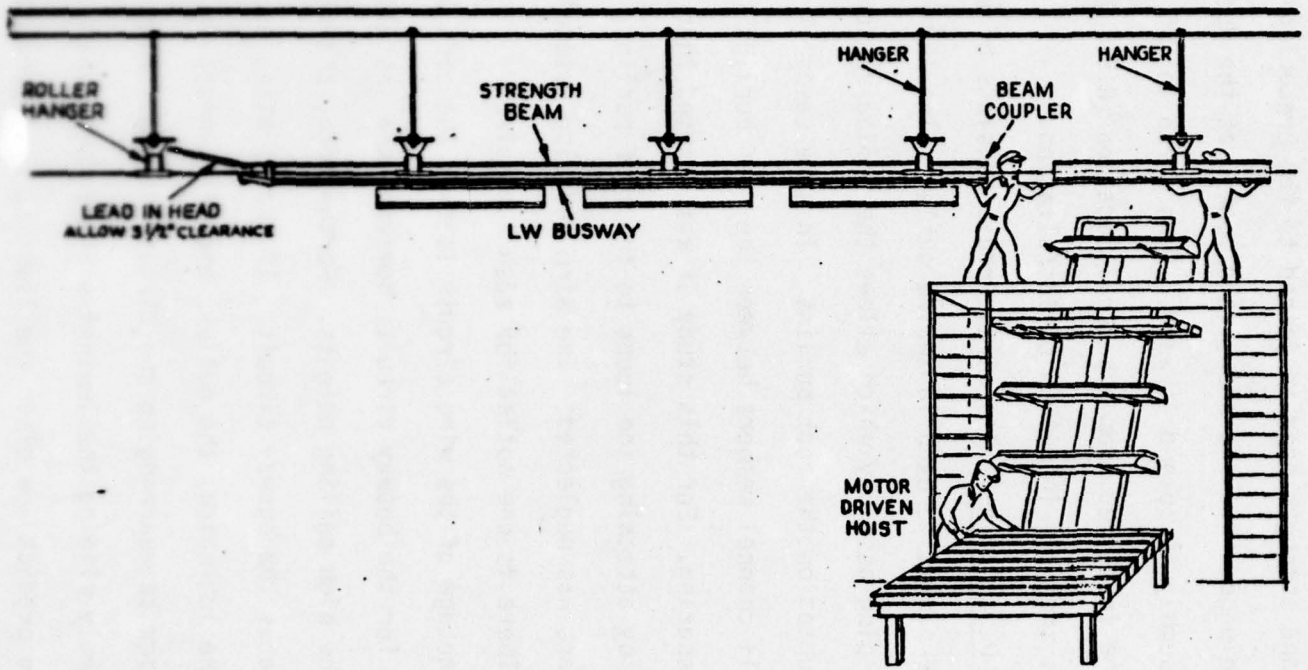


FIGURE E-6-2 BUSWAY ROLL-IN INSTALLATION TECHNIQUE

Cost Comparison. The same design input data was used for both the busway and wire circuit analysis; therefore, both designs contain an identical number of luminaires and circuits.

The following cost data was used for the busway circuit analysis:

1. Luminaire cost = $104.00 ea
2. Accessory cost = $7.60 ea

   The accessory cost includes the cost of the hook, cord, and plug assembly.
3. Lamp cost = $30.00 ea
4. Circuit cost:

   Operating area = $1,326.00 ea

   General storage and mechanized areas = $2,067.00 ea

The circuit cost includes the cost of the panel, the wire and conduit from panel to busway, the busway assembly, and all installation costs including the installation of the luminaire. See Appendix E-4 for a detailed description of how the circuit costs were developed.

The following cost data was used for the wire circuit analysis:

1. Luminaire cost = $104.00 ea
2. Accessory cost = $7.20 ea

   The accessory cost includes the cost of the wire and plug assembly.
3. Lamp cost = $30.00 ea
4. Hanging cost = $18.75 ea

   The hanging cost is the cost to hang the luminaire. This includes installing the hook to the roof purlins, hanging the luminaire, and connecting the luminaire to the outlet.

5. Outlet cost = $12.50 ea

   The outlet cost is the cost for material and installation of the outlet.

6. Circuit cost:

   Operating area = $706.00 ea

   General storage and mechanized areas = $1,547.00 ea

   The circuit cost includes the cost of the panel, wire and conduit to the outlet, plus the installation cost. This cost was computed in the same manner as shown in Appendix E-4.

The LGHTECON computer program was used to compute the design and cost results. The cost results were converted to an annual cost assuming a zero salvage value after 25 years. The results for Case 1, the operating area comparison, are shown in Table E-6-1. The results for Case 2, the general storage and mechanized areas are shown in Table E-6-2.

The results show that the busway circuit is economically competitive with the wire circuit. Due to the flexibility of the busway circuit, it was selected for use in the design study. It is important to stress that although the busway was found to be more expensive, an economic value was not assigned to circuit flexibility.

TABLE E-6-1

ECONOMIC COMPARISON, BUSWAY VERSUS WIRE CIRCUIT FOR CASE 1

(OPERATING AREA)

ITEM	BUSWAY CIRCUIT	WIRE CIRCUIT
Number Of Luminaires	721	721
Number Of Circuits	53	53
Luminaire Cost	$ 74,984.00	$ 74,984.00
Accessory Cost	$ 5,479.60	$ 5,191.20
Lamp Cost	$ 21,630.00	$ 21,630.00
Hanging Cost	$ 0.00	$ 13,518.75
Outlet Cost	$ 0.00	$ 9,012.50
Circuit Cost	$ 70,278.00	$ 37,418.00
Spot Replacement Cost	$ 4,858.96	$ 4,858.96
Ballast Replacement Cost	$ 3,779.19	$ 3,779.19
Cost To Clean Luminaire	$ 539.88	$ 539.88
Energy Cost	$ 76,506.00	$ 76,506.00
Total Annual Cost	$104,674.21	$103,504.52
Cost Per 1000 Cu Ft	$ 8.01	$ 7.92

TABLE E-6-2

ECONOMIC COMPARISON, BUSWAY VERSUS WIRE CIRCUIT FOR CASE 2

(30 FOOT GENERAL STORAGE & MECHANIZED AREA)

ITEM	BUSWAY CIRCUIT	WIRE CIRCUIT
Number Of Luminaires	1153	1153
Number Of Circuits	84	84
Luminaire Cost	$119,912.00	$119,912.00
Accessory Cost	$ 8,762.80	$ 8,301.60
Lamp Cost	$ 34,590.00	$ 34,590.00
Hanging Cost	$ 0.00	$ 21,618.75
Outlet Cost	$ 0.00	$ 14,412.50
Circuit Cost	$173,651.00	$129,924.00
Spot Replacement Cost	$ 7,770.30	$ 7,770.30
Ballast Replacement Cost	$ 6,043.56	$ 6,043.56
Cost To Clean Luminaire	$ 863.37	$ 863.37
Energy Cost	$122,345.92	$122,345.92
Total Annual Cost	$174,141.16	$173,242.51
Cost Per 1000 Cu Ft	$ 3.33	$ 3.31

APPENDIX E-7

EMERGENCY LIGHTING SYSTEM CIRCUIT DESIGN AND COST CALCULATIONS

The emergency lighting system circuit design and cost calculations are presented in this appendix. The assumed circuit arrangement for the main, feeder, and branch circuits are shown in Figure E-7-1. In order to keep the voltage loss to a minimum in the main circuit, the voltage is stepped up to 4160 volts. A 50 KVA, 3ϕ, 4160/480/277 volt step down transformer is required to step the voltage down at locations, 1B, 2B, 3B, 4B, and 5B (see Figure E-7-1). Large conductor single phase 277 volt feeders would run to panel boards located at A, B, and C (see Figure E-7-1).

Only the design and cost calculations for the operating area emergency lighting circuits are shown. The design and cost calculations for the other areas were done in a similar manner and the results are presented in Table E-7-1.

Determine the wire sizes for the branch circuits:

Selected lamp voltage = 277 volts

Selected lamp wattage = 250 watts

Assumed power factor = 0.95

Design for a 2% voltage drop:

Voltage drop allowable = 5.54 volts

Current per lamp = 0.95 amps

Design lengths (see Figure E-7-1):

A1, A2, A7 = 523 ft

A3, A4, A6 = 448 ft

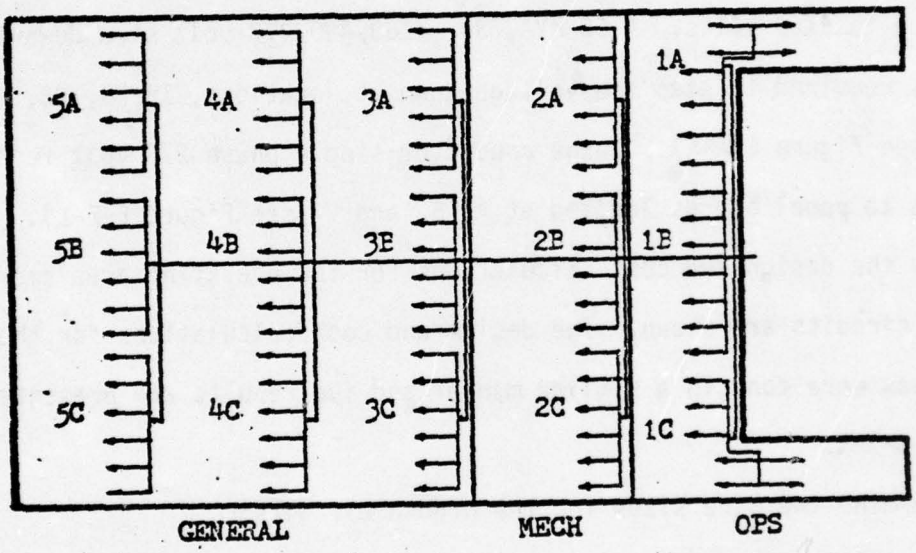


FIGURE E-7-1 EMERGENCY LIGHTING CIRCUIT ARRANGEMENT

A5 = 373 ft

Voltage drop factor and wire selection:

For A1, A2, A7

5.54/(9.5)(5.23) = 0.11150

Select #6 wire (0.0948)

For X2, X5

5.54/(9.5)(4.48) = 0.13017

Select #6 wire (0.0948)

For X3, X4

5.54/(9.5)(3.73) = 0.15634

Select #8 wire (0.1473)

Determine branch circuit cost:

Panel boards at A and C

Panel NHB, 480V, 1Φ, 100A = $45.00

Main breaker, 1TED-4 = $100.00

7 circuit breakers @ $12.80 ea = $89.00

2 blanks @ $3.95 ea = $7.90

Installation = $120.00

Total cost for A and C = $750.00

Panel board at B:

Panel NHB, 480V, 1Φ, 100A = $45.00

Main breaker, 1TED-4 = $100.00

8 circuit breakers @ $12.80 ea = $102.40

2 blanks @ $3.95 ea = $7.90

Installation = $120.00

Total cost for B = $375.30

Wire cost:

Total length of #6 wire = 14,572 ft

Total length of #8 wire = 3,060 ft

Cost of #6 wire = 14,572(0.31) = $4,517.32

Cost of #8 wire = 3,060(0.28) = $856.80

Total wire cost = $5,374.12

Conduit cost:

Use 3/4 in conduit

Length = 3,362 ft @ $1.32 per ft

Total conduit cost = $4,437.84

Total branch circuit cost = $10,937.26

Determine feeder circuit cost:

Transformer cost, 1-4160/480/277, 50 KVA, 3Φ = $1,560.00

Protective device, 3Φ = $1,125

Wire costs for A and C:

Use #4/0 wire @ $2.00 per ft

Length = 2080 ft

Wire cost = $4,160.00

Conduit cost for A and C:

Use 2 in conduit @ $2.50 per ft

Length = 1,040 ft

Conduit cost = $2,600.00

Wire cost for B:

Use #6 wire @ $0.31 per ft

Length = 100 ft

Wire cost = $31.00

Conduit cost for B:

Use 3/4 in conduit @ $1.32 per ft

Length = 50 ft

Conduit cost = $66.00

Total feeder circuit cost = $9,547.00

Determine main feeder cost:

Transformer, 250 KVA, 3Φ = $5,300.00

Protective device, 3Φ, 250 KVA = $2,250.00

Wire costs:

Use #4 wire @ $1.00 per ft

Length = 4,386 ft

Wire cost = $4,386.00

Conduit costs:

Use 2 in conduit

Length = 1,462 ft

Conduit cost = $3,655.00

Splice taps = $1,140.00

Total main feeder cost = $16,731.00

Total main feeder cost for operating area = $3,346.20

Total circuit cost = $23,830.46

Total cost per circuit = $1083.00

TABLE E-7-1

EMERGENCY LIGHTING CIRCUIT COSTS

AREA	COST PER CIRCUIT
Operating Area	$1083.00
30 Ft Mech & Gen Storage Area	$ 811.00
40 Ft Mech & Gen Storage Area	$ 911.00
50 Ft Mech & Gen Storage Area	$1010.00
60 Ft Mech & Gen Storage Area	$1021.00
Freezer	$ 811.00
Cooler	$ 811.00
Vestibule	$ 811.00

APPENDIX E-8

PURCHASED POWER SYSTEMS COST DATA

This appendix includes tabulated cost data for each of the purchased power (electric chiller) systems studied. For each system, the capital cost and the yearly operating costs for the chillers, cooling system pumps, and cooling tower are shown and totaled. Then, the building equipment costs associated with the HVAC systems and the building electricity costs for the material handling equipment and lights is added and totaled. An itemized listing of the associated building costs is included at the end of each set of tables.

TABLE E-8-1

30 FOOT BUILDING ELECTRIC CHILLER COSTS

SYST 1 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
1-400 Ton & 3-800 Ton	273,000	10,298	87,467	
Pumps	60,641	770		
Cooling Tower	77,000	2,000		
Sub Total	410,641	13,068	87,467	145,775
Bldg Equip	1,887,437	17,215	1,018,989	
Total	2,298,078	30,283	1,106,456	1,389,918
SYST 1 OPEN				
1-400 Ton & 3-800 Ton	312,000	10,298	81,691	
Pumps	60,641	770		
Cooling Tower	77,000	2,000		
Sub Total	449,641	13,068	81,691	144,295
Bldg Equip	1,887,437	17,215	1,018,989	
Total	2,337,078	30,283	1,100,680	1,388,439
* SYST 2 HERMETIC				
2-525 Ton & 2-950 Ton	275,600	9,400	81,268	
Pumps	60,849	770		
Cooling Tower	86,000	2,000		
Sub Total	422,449	12,170	81,268	139,979
Bldg Equip	1,887,437	17,215	1,018,989	
Total	2,309,886	29,385	1,100,257	1,384,122

* Best Electric Chiller System, 30 Foot Building

TABLE E-8-1 CONTINUED

SYST 2 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-525 Ton & 2-950 Ton	312,800	9,400	77,683	
Pumps	60,849	770		
Cooling Tower	86,000	2,000		
Sub Total	459,649	12,170	77,683	140,492
Bldg Equip	1,887,437	17,215	1,018,989	
Total	2,347,086	29,385	1,096,672	1,384,635
SYST 3 HERMETIC				
3-1050 Ton	256,800	11,016	89,732	
Pumps	62,738	660		
Cooling Tower	86,000	2,000		
Sub Total	405,538	13,676	89,732	148,086
Bldg Equip	1,887,437	17,215	1,018,989	
Total	2,292,975	30,891	1,108,721	1,392,229
SYST 3 OPEN				
3-1050 Ton	316,800	11,016	83,785	
Pumps	62,738	660		
Cooling Tower	86,000	2,000		
Sub Total	465,538	13,676	83,785	148,749
Bldg Equip	1,887,437	17,215	1,018,989	
Total	2,352,975	30,891	1,102,774	1,392,892

TABLE E-8-1 CONTINUED

SYST 4 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-675 Ton	268,000	10,963	92,805	
Pumps	59,253	770		
Cooling Tower	77,000	2,000		
Sub Total	404,253	13,733	92,805	151,074
Bldg Equip	1,887,437	17,215	1,018,989	
Total	2,291,690	30,948	1,111,794	1,395,217
SYST 4 OPEN				
4-675 Ton	293,600	10,963	85,505	
Pumps	59,253	770		
Cooling Tower	77,000	2,000		
Sub Total	429,853	13,773	85,505	146,594
Bldg Equip	1,887,437	17,215	1,018,989	
Total	2,317,290	30,948	1,104,494	1,390,738
BLDG ELEC COSTS			1,018,989	
Boiler System	18,513	0		
Air Handling Units	320,334	10,640		
Ducts & Piping	238,374	0		
Fans	236,848	3,930		
Backup Power	872,513	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,887,437	17,215	1,018,989	1,244,143

TABLE E-8-2

40 FOOT BUILDING ELECTIC CHILLER COSTS

* SYST 1 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
1-400 Ton & 3-725 Ton	254,700	8,613	74,043	
Pumps	57,389	770		
Cooling Tower	76,000	2,000		
Sub Total	388,089	11,383	74,043	128,182
Bldg Equip	1,836,528	15,305	933,703	
Total	2,224,617	26,688	1,007,746	1,279,520
SYST 1 OPEN				
1-400 Ton & 3-725 Ton	284,300	8,613	68,990	
Pumps	57,389	770		
Cooling Tower	76,000	2,000		
Sub Total	417,689	11,383	68,990	126,390
Bldg Equip	1,836,528	15,305	933,703	
Total	2,254,217	26,688	1,002,693	1,277,728
SYST 2 HERMETIC				
2-400 Ton & 2-1050 Ton	266,600	9,797	73,984	
Pumps	65,886	770		
Cooling Tower	77,000	2,000		
Sub Total	409,486	12,567	73,984	131,664
Bldg Equip	1,836,528	15,305	933,703	
Total	2,246,014	27,872	1,007,687	1,283,002

* Best Electric Chiller System, 40 Foot Building

TABLE E-8-2 CONTINUED

SYST 2 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-1050 Ton	313,000	9,797	70,390	
Pumps	65,886	770		
Cooling Tower	77,000	2,000		
Sub Total	455,886	12,567	70,390	133,182
Bldg Equip	1,836,528	15,305	933,703	
Total	2,292,414	27,872	1,004,093	1,284,520
SYST 3 HERMETIC				
3-950 Ton	254,700	9,792	73,996	
Pumps	59,508	660		
Cooling Tower	77,000	2,000		
Sub Total	391,208	12,452	73,996	129,547
Bldg Equip	1,836,528	15,305	933,703	
Total	2,227,736	27,757	1,007,699	1,280,885
SYST 3 OPEN				
3-950 Ton	291,300	9,792	69,162	
Pumps	59,508	660		
Cooling Tower	77,000	2,000		
Sub Total	427,808	12,452	69,162	128,746
Bldg Equip	1,836,528	15,305	933,703	
Total	2,264,336	27,757	1,002,865	1,280,084

TABLE E-8-2 CONTINUED

SYST 4 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-620 Ton	230,000	9,472	77,402	
Pumps	54,906	770		
Cooling Tower	76,000	2,000		
Sub Total	360,906	12,242	77,402	129,405
Bldg Equip	1,836,528	15,305	933,703	
Total	2,197,434	27,547	1,011,105	1,280,743
SYST 4 OPEN				
4-620 Ton	269,200	9,472	73,320	
Pumps	54,906	770		
Cooling Tower	76,000	2,000		
Sub Total	400,106	12,242	73,320	129,646
Bldg Equip	1,836,528	15,305	933,703	
Total	2,236,634	27,547	1,007,023	1,280,980
BLDG ELEC COSTS			933,703	
Boiler System	22,236	0		
Air Handling Units	276,348	9,360		
Ducts & Piping	224,259	0		
Fans	243,430	3,300		
Backup Power	869,400	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,836,528	15,305	933,703	1,151,338

TABLE E-8-3

50 FOOT BUILDING ELECTRIC CHILLER COSTS

SYST 1 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
1-400 Ton & 3-675 Ton	248,700	7,947	65,989	
Pumps	55,756	770		
Cooling Tower	76,000	2,000		
Sub Total	380,456	10,717	65,989	118,621
Bldg Equip	1,878,934	16,555	905,334	
Total	2,259,390	27,272	971,323	1,247,512
SYST 1 OPEN				
1-400 Ton & 3-675 Ton	271,100	7,947	60,979	
Pumps	55,756	770		
Cooling Tower	76,000	2,000		
Sub Total	402,856	10,717	60,979	116,079
Bldg Equip	1,878,934	16,555	905,334	
Total	2,281,790	27,272	966,313	1,244,970
* SYST 2 HERMETIC				
2-400 Ton & 2-950 Ton	265,200	7,720	58,707	
Pumps	58,316	770		
Cooling Tower	76,000	2,000		
Sub Total	399,516	10,490	58,707	113,212
Bldg Equip	1,878,934	16,555	905,334	
Total	2,278,450	27,049	964,041	1,242,102

* Best Electric Chiller System, 50 Foot Building

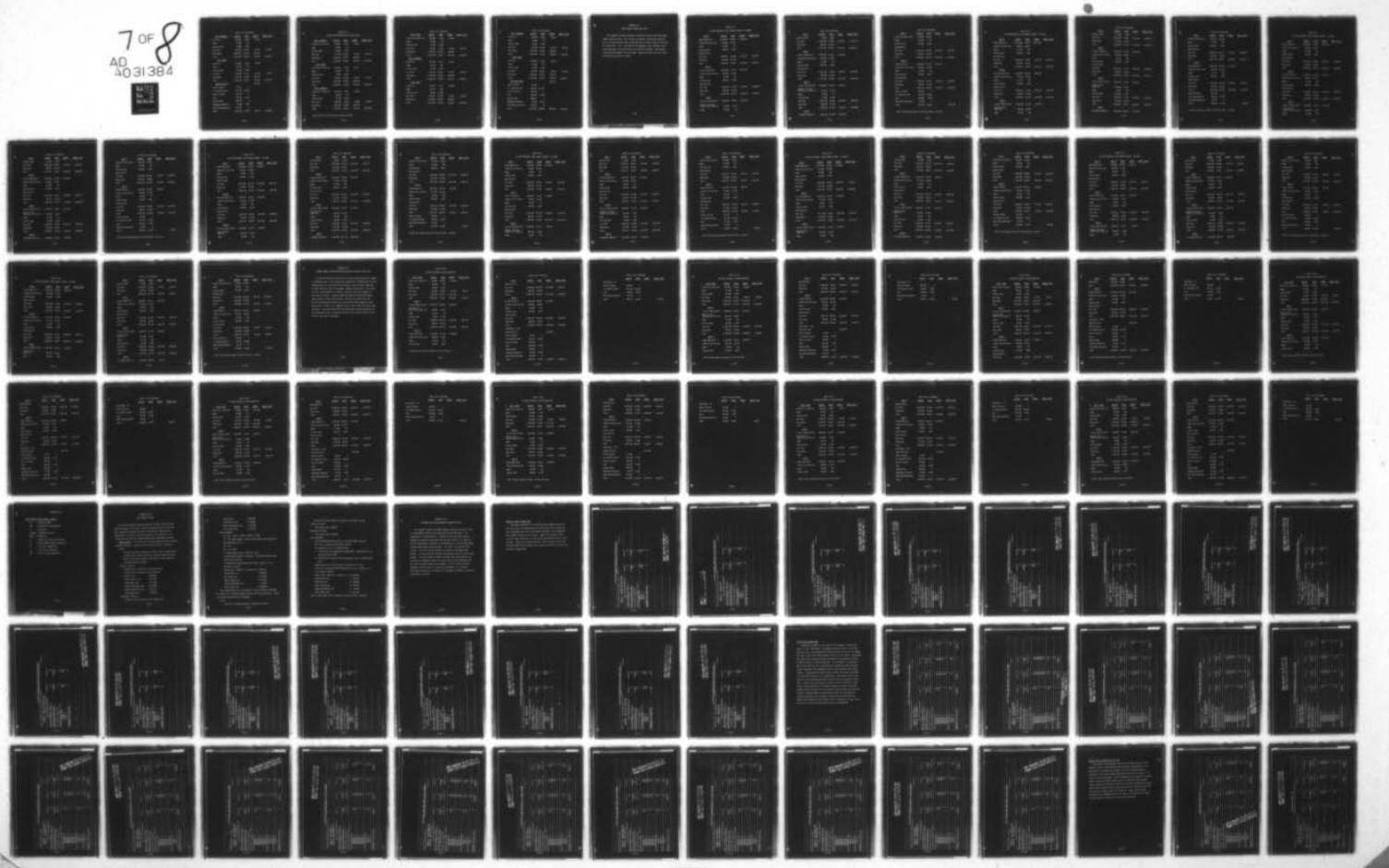
TABLE E-8-3 CONTINUED

SYST 2 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-950 Ton	296,000	7,720	55,951	
Pumps	58,316	770		
Cooling Tower	76,000	2,000		
Sub Total	430,316	10,490	55,951	113,849
Bldg Equip	1,878,934	16,555	905,334	
Total	2,309,250	27,049	961,285	1,242,740
SYST 3 HERMETIC				
3-950 Ton	254,700	9,574	74,284	
Pumps	59,509	660		
Cooling Tower	76,000	2,000		
Sub Total	390,209	12,234	74,284	129,507
Bldg Equip	1,878,934	16,555	905,334	
Total	2,269,143	28,789	979,618	1,258,398
SYST 3 OPEN				
3-950 Ton	291,300	9,574	69,409	
Pumps	59,509	660		
Cooling Tower	76,000	2,000		
Sub Total	426,809	12,234	69,409	128,665
Bldg Equip	1,878,934	16,555	905,334	
Total	2,305,743	28,789	974,743	1,257,556

AD-A031 384 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCH--ETC F/G 13/2
A GENERAL WAREHOUSE MODULE CONCEPTUAL DESIGN AND COST ANALYSIS.--ETC(U)
SEP 76 R T ALEXANDER, T J CARMICHAEL

UNCLASSIFIED GCE/MC/76S-1-VOL-2 NL

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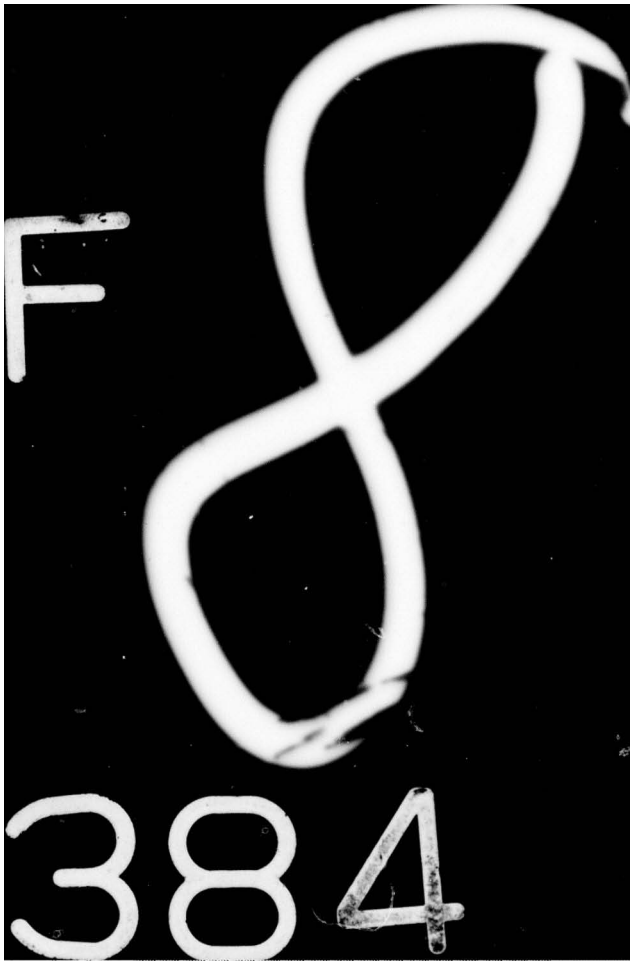

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TABLE E-8-3 CONTINUED

SYST 4 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-575 Ton	222,400	8,801	67,150	
Pumps	53,086	770		
Cooling Tower	76,000	2,000		
Sub Total	351,486	11,571	67,150	117,444
Bldg Equip	1,878,934	16,555	905,334	
Total	2,230,420	28,126	972,484	1,246,335
SYST 4 OPEN				
4-575 Ton	258,800	8,801	64,858	
Pumps	53,086	770		
Cooling Tower	76,000	2,000		
Sub Total	387,886	11,571	64,858	119,162
Bldg Equip	1,878,934	16,555	905,334	
Total	2,266,820	28,126	970,192	1,248,053
BLDG ELEC COSTS			905,334	
Boiler System	22,236	0		
Air Handling Units	287,438	10,640		
Ducts & Piping	221,055	0		
Fans	277,950	3,270		
Backup Power	869,400	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,878,934	16,555	905,334	1,128,891

TABLE E-8-4

60 FOOT BUILDING ELECTRIC CHILLER COSTS

SYST 1 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
1-350 Ton & 3-675 Ton	237,900	7,324	61,183	
Pumps	56,256	770		
Cooling Tower	76,000	2,000		
Sub Total	370,156	10,094	61,183	112,057
Bldg Equip	1,810,050	18,495	869,158	
Total	2,180,206	28,589	930,341	1,199,123
SYST 1 OPEN				
1-350 Ton & 3-675 Ton	262,100	7,324	56,477	
Pumps	56,256	770		
Cooling Tower	76,000	2,000		
Sub Total	394,356	10,094	56,477	110,017
Bldg Equip	1,810,050	18,495	869,158	
Total	2,204,406	28,589	925,635	1,197,083
* SYST 2 HERMETIC				
2-400 Ton & 2-950 Ton	265,200	7,029	53,089	
Pumps	58,558	770		
Cooling Tower	77,000	2,000		
Sub Total	400,758	9,799	53,089	107,040
Bldg Equip	1,810,050	18,495	869,158	
Total	2,210,808	28,294	922,247	1,194,106

* Best Electric Chiller System, 60 Foot Building

TABLE E-8-4 CONTINUED

SYST 2 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-950 Ton	296,000	7,029	50,626	
Pumps	58,558	770		
Cooling Tower	77,000	2,000		
Sub Total	431,558	9,799	50,626	107,970
Bldg Equip	1,810,050	18,495	869,158	
Total	2,241,608	28,294	919,784	1,195,036
SYST 3 HERMETIC				
3-850 Ton	247,800	8,735	62,073	
Pumps	61,152	660		
Cooling Tower	76,000	2,000		
Sub Total	384,952	11,395	62,073	115,878
Bldg Equip	1,810,050	18,495	869,158	
Total	2,195,002	29,890	931,231	1,202,944
SYST 3 OPEN				
3-850 Ton	286,230	8,735	58,380	
Pumps	61,152	660		
Cooling Tower	76,000	2,000		
Sub Total	423,382	11,395	58,380	116,419
Bldg Equip	1,810,050	18,495	869,158	
Total	2,233,432	29,890	927,538	1,203,485

TABLE E-8-4 CONTINUED

SYST 4 HERMETIC	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-575 Ton	222,400	8,158	60,192	
Pumps	53,086	770		
Cooling Tower	76,000	2,000		
Sub Total	351,486	10,928	60,192	109,843
Bldg Equip	1,810,050	18,495	869,158	
Total	2,161,536	29,423	929,350	1,196,909
SYST 4 OPEN				
4-575 Ton	258,800	8,158	58,105	
Pumps	53,086	770		
Cooling Tower	76,000	2,000		
Sub Total	387,886	10,928	58,105	111,766
Bldg Equip	1,810,050	18,495	869,158	
Total	2,197,936	29,423	927,263	1,145,171
BLDG ELEC COSTS			869,158	
Boiler System	30,335	0		
Air Handling Units	314,800	11,920		
Ducts & Piping	232,000	0		
Fans	334,050	3,930		
Backup Power	698,010	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,810,050	18,495	869,158	1,087,066

APPENDIX E-9

TOTAL ENERGY SYSTEMS COST DATA

This appendix includes tabulated cost data for each of the seven total energy systems studied. This includes evaluations of buildings having 20 acres air-conditioned/30 acres ventilated, and buildings having all 50 acres air-conditioned. First, cost data for the generator sets, chillers, cooling system pumps, and cooling tower are listed and totaled. Then, associated building equipment costs are added. These associated costs are listed at the end of each set of tables.

TABLE E-9-1

30 FOOT BUILDING, TOTAL ENERGY SYSTEMS - 20 ACRES

SYST A	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-DDA 3000 KW GT	2,376,000	34,665	1,577,864	
3-1148 Ton AB Chillers	339,600	12,454		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,948,150	50,834	1,577,864	1,953,496
Bldg Equip	840,970	14,570		
Total	3,789,120	65,404	1,577,864	2,060,716
SYST B				
11-Solar 800 KW GT	2,024,000	57,775	1,679,333	
3-1148 Ton AB Chillers	339,600	12,454		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,596,150	73,944	1,679,333	2,039,295
Bldg Equip	840,970	14,570		
Total	3,437,120	88,514	1,679,333	2,146,515
SYST C				
9-Solar 1200 KW GT/ST	2,520,000	60,903	1,145,911	
Hermetic Chillers 2-525 Ton & 2-950 Ton	275,600	9,316		
Pumps	60,849	770		

TABLE E-9-1 CONTINUED

SYST C	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Cooling Tower	77,000	2,000		
Sub Total	2,933,449	72,989	1,145,911	1,743,197
Bldg Equip	840,970	14,570		
Total	3,774,419	87,559	1,145,911	1,850,417
SYST D				
4-Solar 2500 KW GT	2,300,000	57,775	1,799,720	
3-1148 Ton AB Chillers	339,600	12,454		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,872,150	73,944	1,799,720	2,190,089
Bldg Equip	840,970	14,570		
Total	3,713,120	88,514	1,799,720	2,297,308
SYST E				
4-Solar 3750 KW GT/ST	3,500,000	60,903	1,248,727	
Hermetic Chillers 2-525 Ton & 2-950 Ton	275,600	9,316		
Pumps	60,849	770		
Cooling Tower	77,000	2,000		
Sub Total	3,913,449	72,989	1,248,727	1,752,861
Bldg Equip	840,970	14,570		
Total	4,754,419	87,559	1,248,727	1,860,080
SYST F				
13-Cummins 690 KW D	1,883,700	127,276	1,063,736	

TABLE E-9-1 CONTINUED

SYST F	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
3-1148 Ton AB Chillers	339,600	12,454		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,455,850	143,445	1,063,736	1,477,742
Bldg Equip	840,970	14,570		
Total	3,296,820	158,015	1,063,736	1,584,962
* SYST G				
12-DDA 795 KW D	2,094,030	127,272	1,024,731	
3-1148 Ton AB Chillers	339,600	12,454		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,666,180	143,441	1,024,731	1,461,905
Bldg Equip	840,970	14,570		
Total	3,507,150	158,011	1,024,731	1,569,125
Ducts & Piping	238,374	0		
Air Handling Units	320,334	10,640		
Fans	236,848	3,930		
Mech Room Substation	45,414	0		
Total	840,970	14,570		107,220

* Best Total Energy System, 30 Foot Building - 20 Acres.

TABLE E-9-2

30 FOOT BUILDING, TOTAL ENERGY SYSTEMS - 50 ACRES

SYST A	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-DDA 3000 KW GT	2,376,000	34,971	1,347,733	
4-960 Ton AB Chillers	387,600	15,036		
Pumps	87,114	935		
Cooling Tower	180,000	3,000		
Waste Boilers				
Sub Total	3,030,714	53,942	1,347,733	1,735,569
Bldg Equip	887,802	17,040		
Total	3,918,516	70,982	1,347,733	1,850,418
SYST B				
11-Solar 800 KW GT	2,024,000	58,220	1,692,560	
4-960 Ton AB Chillers	387,600	15,036		
Pumps	87,114	935		
Cooling Tower	180,000	3,000		
Waste Boilers				
Sub Total	2,678,714	77,191	1,692,560	2,064,865
Bldg Equip	887,802	17,040		
Total	3,566,516	94,231	1,692,560	2,179,714
SYST C				
9-Solar 1200 KW GT/ST	2,520,000	61,984	1,111,801	
Open Chillers 4-950 Ton	388,400	12,667		
Pumps	78,399	880		

TABLE E-9-2 CONTINUED

SYST C	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Cooling Tower	114,000	2,000		
Sub Total	3,100,799	77,531	1,111,801	1,530,947
Bldg Equip	887,802	17,040		
Total	3,988,601	94,571	1,111,801	1,645,796
SYST D				
4-Solar 2500 KW GT	2,300,000	58,474	1,806,529	
4-960 Ton AB Chillers	387,600	15,036		
Pumps	87,114	935		
Cooling Tower	180,000	3,000		
Waste Boilers				
Sub Total	2,954,714	77,445	1,806,529	2,209,496
Bldg Equip	887,802	17,040		
Total	3,842,516	94,485	1,806,529	2,324,345
SYST E				
4-Solar 3750 KW GT/ST	3,500,000	61,984	1,265,811	
Open Chillers 4-950 Ton	388,400	12,667		
Pumps	78,399	880		
Cooling Tower	114,000	2,000		
Sub Total	4,080,799	77,531	1,265,811	1,792,924
Bldg Equip	887,802	17,040		
Total	4,968,601	94,571	1,265,811	1,907,773
SYST F				
13-Cummins 690 KW D	1,883,700	128,246	1,112,656	

TABLE E-9-2 CONTINUED

SYST F	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-960 Ton AB Chillers	387,600	15,036		
Pumps	87,114	935		
Cooling Tower	180,000	3,000		
Waste Boilers				
Sub Total	2,538,414	147,217	1,112,656	1,539,530
Bldg Equip	887,802	17,040		
Total	3,426,216	164,257	1,112,656	1,654,379
* SYST G				
12-DDA 795 KW D	2,094,030	128,242	1,073,064	
4-960 Ton AB Chillers	387,600	15,036		
Pumps	87,114	935		
Cooling Tower	180,000	3,000		
Waste Boilers				
Sub Total	2,748,744	147,214	1,073,064	1,523,107
Bldg Equip	887,802	17,040		
Total	3,636,546	164,254	1,073,064	1,637,956
Ducts & Piping	351,654	0		
Air Handling Units	490,734	17,040		
Mech Room Substation	45,414	0		
Total	887,802	17,040		114,849

* Best Total Energy System, 30 Foot Building - 50 Acres

TABLE E-9-3

40 FOOT BUILDING, TOTAL ENERGY SYSTEMS - 20 ACRES

SYST A	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-DDA 3000 KW GT	2,376,000	31,397	1,425,195	
3-960 Ton AB Chillers	290,700	11,576		
Pumps	66,348	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,873,048	46,687	1,425,195	1,788,406
Bldg Equip	789,451	12,660		
Total	3,662,499	59,347	1,425,195	1,888,040
SYST B				
9-Solar 800 KW GT	1,656,000	52,328	1,545,372	
3-960 Ton AB Chillers	290,700	11,576		
Pumps	66,348	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,153,048	67,619	1,545,372	1,850,192
Bldg Equip	789,451	12,660		
Total	2,942,499	80,279	1,545,372	1,949,826
SYST C				
8-Solar 1200 KW GT/ST	2,240,000	54,871	1,041,598	
Open Chillers 1-400 Ton & 3-725 Ton	284,300	8,575		
Pumps	57,389	770		

TABLE E-9-3 CONTINUED

SYST C	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Cooling Tower	76,000	2,000		
Sub Total	2,657,689	66,216	1,041,598	1,400,612
Bldg Equip	789,451	12,660		
Total	3,447,140	78,876	1,041,598	1,500,246
SYST D				
4-Solar 2500 KW GT	2,300,000	52,328	1,710,499	
3-960 Ton AB Chillers	290,700	11,576		
Pumps	66,384	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,797,084	67,619	1,710,499	2,086,272
Bldg Equip	789,451	12,660		
Total	3,586,535	80,279	1,710,499	2,185,906
SYST E				
3-Solar 3750 KW GT/ST	2,625,000	54,871	1,158,422	
Open Chillers 1-400 Ton & 3-725 Ton	284,300	8,575		
Pumps	57,389	770		
Cooling Tower	76,000	2,000		
Sub Total	3,042,689	66,216	1,158,422	1,559,851
Bldg Equip	789,451	12,660		
Total	3,832,140	78,876	1,158,422	1,659,485
SYST F				
12-Cummins 690 KW D	1,738,800	115,258	957,643	

TABLE E-9-3 CONTINUED

SYST F	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
3-960 Ton AB Chillers	290,700	11,576		
Pumps	66,384	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,235,884	130,549	957,643	1,334,519
Bldg Equip	781,451	12,660		
Total	3,025,335	143,209	957,643	1,434,153
* SYST G				
10-DDA 795 KW D	1,745,025	115,258	923,806	
3-960 Ton AB Chillers	290,700	11,576		
Pumps	66,384	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,242,109	130,549	923,806	1,301,368
Bldg Equip	789,451	12,660		
Total	3,031,560	143,209	923,806	1,401,002
Ducts & Piping	224,259	0		
Air Handling Units	276,348	9,360		
Fans	243,430	3,300		
Mech Room Substation	45,414	0		
Total	789,451	12,660		99,634

* Best Total Energy System, 40 Foot Building - 20 Acres

TABLE E-9-4

40 FOOT BUILDING, TOTAL ENERGY SYSTEMS - 50 ACRES

SYST A	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-DDA 3000 KW GT	2,376,000	31,576	1,436,939	
4-908 Ton AB Chillers	371,200	12,589		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,997,486	48,100	1,436,939	1,815,272
Bldg Equip	871,229	17,040		
Total	3,868,715	65,140	1,436,939	1,928,295
SYST B				
10-Solar 800 KW GT	1,840,000	52,681	1,550,282	
4-908 Ton AB Chillers	371,200	12,589		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,461,486	69,205	1,550,282	1,890,669
Bldg Equip	871,229	17,040		
Total	3,332,715	86,245	1,550,282	2,003,692
SYST C				
8-Solar 1200 KW GT/ST	2,240,000	55,716	1,055,959	
Open Chillers 4-850 Ton	381,640	11,597		
Pumps	80,450	880		

TABLE E-9-4 CONTINUED

SYST C	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Cooling Tower	96,000	2,000		
Sub Total	2,798,090	70,192	1,055,959	1,434,417
Bldg Equip	871,229	17,040		
Total	3,669,319	87,232	1,055,959	1,547,440
SYST D				
4-Solar 2500 KW GT	2,300,000	52,865	1,713,786	
4-908 Ton AB Chillers	371,200	12,589		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,921,486	69,389	1,713,786	2,105,035
Bldg Equip	871,229	17,040		
Total	3,792,715	86,429	1,713,786	2,218,058
SYST E				
3-Solar 3750 KW GT/ST	2,625,000	55,716	1,171,157	
Open Chillers 4-850 Ton	381,640	11,597		
Pumps	80,450	880		
Cooling Tower	96,000	2,000		
Sub Total	3,183,090	70,192	1,171,157	1,592,030
Bldg Equip	871,229	17,040		
Total	4,054,319	87,232	1,171,157	1,705,053
SYST F				
12-Cummins 690 KW D	1,738,800	115,739	1,007,789	

TABLE E-9-4 CONTINUED

SYST F	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-908 Ton AB Chillers	371,200	12,589		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,360,286	132,263	1,007,789	1,400,084
Bldg Equip	871,229	17,040		
Total	3,231,515	149,303	1,007,789	1,513,107
* SYST G				
11-DDA 795 KW D	1,919,528	115,736	974,166	
4-908 Ton AB Chillers	371,200	12,589		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,541,014	132,260	974,166	1,386,370
Bldg Equip	871,229	17,040		
Total	3,412,243	149,300	974,166	1,499,393
Ducts & Piping	344,987	0		
Air Handling Units	480,828	17,040		
Mech Room Substation	45,414	0		
Total	871,229	17,040		113,023

* Best Total Energy System, 40 Foot Building - 50 Acres

TABLE E-9-5

50 FOOT BUILDING, TOTAL ENERGY SYSTEMS - 20 ACRES

SYST A	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
3-DDA 3000 KW GT	1,782,000	29,989	1,388,617	
3-908 Ton AB Chillers	278,400	10,102		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,265,349	43,806	1,388,617	1,681,996
Bldg Equip	831,857	13,910		
Total	3,097,206	57,716	1,388,617	1,787,552
SYST B				
9-Solar 800 KW GT	1,656,000	49,981	1,469,928	
3-908 Ton AB Chillers	278,400	10,102		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,139,349	63,798	1,469,928	1,769,418
Bldg Equip	831,857	13,910		
Total	2,971,206	77,699	1,469,928	1,874,974
SYST C				
7-Solar 1200 KW GT/ST	1,960,000	52,147	992,259	
Hermetic Chillers 2-400 Ton & 2-950 Ton	265,200	7,678		
Pumps	58,316	770		

TABLE E-9-5 CONTINUED

SYST C	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Cooling Tower	76,000	2,000		
Sub Total	2,359,516	62,595	992,259	1,314,802
Bldg Equip	831,857	13,910		
Total	3,191,373	76,505	992,259	1,420,357
SYST D				
4-Solar 2500 KW GT	2,300,000	49,981	1,674,112	
3-908 Ton AB Chillers	278,400	10,102		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,783,349	63,798	1,674,112	2,044,552
Bldg Equip	831,857	13,910		
Total	3,615,205	77,708	1,674,112	2,150,107
SYST E				
3-Solar 3750 KW GT/ST	2,625,000	52,147	1,122,102	
Hermetic Chillers 2-400 Ton & 2-950 Ton	265,200	7,678		
Pumps	58,316	770		
Cooling Tower	76,000	2,000		
Sub Total	3,024,516	62,595	1,122,102	1,517,908
Bldg Equip	831,857	13,910		
Total	3,856,373	76,505	1,122,102	1,623,464
SYST F				
12-Cummins 690 KW D	1,738,800	110,087	913,033	

TABLE E-9-5 CONTINUED

SYST F	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
3-908 Ton AB Chillers	278,400	10,102		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,222,149	123,904	913,033	1.281.751
Bldg Equip	831,857	13,910		
Total	3,054,006	137,814	913,033	1,387,307
* SYST G				
10-DDA 795 KW D	1,745,025	110,083	880,587	
3-908 Ton AB Chillers	278,400	10,102		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,228,374	123,900	880,587	1,249,987
Bldg Equip	831,857	13,910		
Total	3,060,231	137,810	880,587	1,355,543
Ducts & Piping	221,055	0		
Air Handling Units	287,438	10,640		
Fans	277,950	3,270		
Mech Room Substation	45,414	0		
Total	831,857	13,910		105,556

* Best Total Energy System, 50 Foot Building - 20 Acres

TABLE E-9-6

50 FOOT BUILDING, TOTAL ENERGY SYSTEMS - 50 ACRES

SYST A	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-DDA 3000 KW GT	2,376,000	30,330	1,393,651	
4-908 Ton AB Chillers	371,200	12,045		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,997,486	46,310	1,393,651	1,770,194
Bldg Equip	926,392	19,600		
Total	3,923,878	65,910	1,393,651	1,891,855
SYST B				
9- Solar 800 KW GT	1,656,000	50,515	1,478,698	
4-908 Ton AB Chillers	371,200	12,045		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,277,486	66,495	1,478,698	1,796,104
Bldg Equip	926,392	19,600		
Total	3,203,878	86,095	1,478,698	1,917,765
SYST C				
8-Solar 1200 KW GT/ST	2,240,000	53,355	1,012,672	
Open Chillers 4-850 Ton	381,640	11,046		
Pumps	80,450	880		

TABLE E-9-6 CONTINUED

SYST C	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Cooling Tower	96,000	2,000		
Sub Total	2,798,090	67,281	1,012,672	1,388,219
Bldg Equip	926,392	19,600		
Total	3,724,482	86,881	1,012,672	1,509,880
SYST D				
4-Solar 2500 KW GT	2,300,000	50,725	1,679,391	
4-908 Ton AB Chillers	371,200	12,045		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,921,486	66,705	1,679,391	2,067,956
Bldg Equip	926,392	19,600		
Total	3,847,878	86,305	1,679,391	2,189,617
SYST E				
3-Solar 3750 KW GT/ST	2,625,000	53,355	1,138,205	
Open Chillers 4-850 Ton	381,640	11,046		
Pumps	80,450	880		
Cooling Tower	96,000	2,000		
Sub Total	3,183,090	67,281	1,138,205	1,556,167
Bldg Equip	926,392	19,600		
Total	4,109,482	86,881	1,138,205	1,677,828
SYST F				
12-Cummins 690 KW D	1,738,000	110,879	970,746	

TABLE E-9-6 CONTINUED

SYST F	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-908 Ton AB Chillers	371,200	12,045		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,359,486	126,860	970,746	1,357,550
Bldg Equip	926,392	19,600		
Total	3,285,878	146,460	970,746	1,479,211
* SYST G				
10-DDA 795 KW D	1,745,025	110,877	937,831	
4-908 Ton AB Chillers	371,200	12,045		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,366,511	126,857	937,831	1,334,407
Bldg Equip	926,392	19,600		
Total	3,292,903	146,457	937,831	1,456,068
Ducts & Piping	360,748	0		
Air Handling Units	520,230	19,600		
Mech Room Substation	45,414	0		
Total	926,392	19,600		121,661

* Best Total Energy System, 50 Foot Building - 50 Acres

TABLE E-9-7

60 FOOT BUILDING, TOTAL ENERGY SYSTEM - 20 ACRES

SYST A	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
3-DDA 3000 KW GT	1,782,000	28,486	1,351,702	
3-908 Ton AB Chillers	278,400	9,441		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,265,349	41,642	1,351,702	1,642,917
Bldg Equip	926,264	15,850		
Total	3,191,613	57,492	1,351,702	1,761,598
SYST B				
8-Solar 800 KW GT	1,472,000	47,477	1,387,850	
3-908 Ton AB Chillers	278,400	9,441		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	1,955,349	60,633	1,387,850	1,663,904
Bldg Equip	926,264	15,850		
Total	2,881,613	76,483	1,387,850	1,782,585
SYST C				
7-Solar 1200 KW GT/ST	1,960,000	49,415	941,599	
Hermetic Chillers 2-400 Ton & 2-950 Ton	265,200	7,009		
Pumps	58,558	770		

TABLE E-9-7 CONTINUED

SYST C	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Cooling Tower	77,000	2,000		
Sub Total	2,360,758	59,194	941,599	1,260,877
Bldg Equip	926,264	15,850		
Total	3,287,022	75,044	941,599	1,379,558
SYST D				
4-Solar 2500 KW GT	2,300,000	47,477	1,555,738	
3-908 Ton AB Chillers	278,400	9,441		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,783,349	60,633	1,555,738	1,923,013
Bldg Equip	926,264	15,850		
Total	3,709,613	76,483	1,555,738	2,041,694
SYST E				
3-Solar 3750 KW GT/ST	2,625,000	49,415	1,040,370	
Hermetic Chillers 2-400 Ton & 2-950 Ton	265,200	7,009		
Pumps	64,949	770		
Cooling Tower	77,000	2,000		
Sub Total	3,032,149	59,194	1,040,370	1,433.616
Bldg Equip	926,264	15,850		
Total	3,958,413	75,044	1,040,370	1,552,297
SYST F				
11-Cummins 690 KW D	1,593,900	104,567	866,184	

TABLE E-9-7 CONTINUED

SYST F	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
3-908 Ton AB Chillers	278,400	9,441		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,077,249	117,723	866,184	1,212,757
Bldg Equip	926,264	15,850		
Total	3,003,513	133,573	866,184	1,331,438
* SYST G				
9-DDA 795 KW D	1,570,523	104,565	834,933	
3-908 Ton AB Chillers	278,400	9,441		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,053,872	117,721	834,933	1,178,629
Bldg Equip	926,264	15,850		
Total	2,980,136	133,571	834,933	1,297,610
Ducts & Piping	232,000	0		
Air Handling Units	314,800	11,920		
Fans	334,050	3,930		
Mech Room Substation	45,414	0		
Total	926,264	15,850		118,681

* Best Total Energy System, 60 Foot Building - 20 Acres

TABLE E-9-8

60 FOOT BUILDING, TOTAL ENERGY SYSTEM - 50 ACRES

SYST A	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
3-DDA 3000 KW GT	1,782,000	28,805	1,356,255	
4-908 Ton AB Chillers	371,200	11,155		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,403,486	43,895	1,356,255	1,664,942
Bldg Equip	964,699	20,880		
Total	3,368,185	64,775	1,356,255	1,792,920
SYST B				
8-Solar 800 KW GT	1,472,000	47,983	1,396,999	
4-908 Ton AB Chillers	371,200	11,155		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,093,486	63,073	1,396,999	1,690,711
Bldg Equip	964,699	20,880		
Total	3,058,185	83,953	1,396,999	1,818,689
SYST C				
7-Solar 1200 KW GT/ST	1,960,000	50,532	962,942	
Open Chillers 4-850 Ton	381,640	10,447		
Pumps	80,450	880		

TABLE E-9-8 CONTINUED

SYST C	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Cooling Tower	96,000	2,000		
Sub Total	2,518,090	63,859	962,942	1,304,219
Bldg Equip	964,699	20,880		
Total	3,482,789	84,739	962,942	1,432,197
SYST D				
4-Solar 2500 KW GT	2,300,000	48,170	1,561,405	
4-908 Ton AB Chillers	371,200	11,155		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,921,486	63,260	1,561,405	1,946,525
Bldg Equip	964,699	20,880		
Total	3,886,185	84,140	1,561,405	2,074,503
SYST E				
3-Solar 3750 KW GT/ST	2,625,000	50,532	1,052,400	
Open Chillers 4-850 Ton	381,640	10,477		
Pumps	80,450	880		
Cooling Tower	96,000	2,000		
Sub Total	3,183,090	63,859	1,052,400	1,466,940
Bldg Equip	964,699	20,880		
Total	4,147,789	84,739	1,052,400	1,594,918
SYST F				
11-Cummins 690 KW D	1,593,900	105,309	920,747	

TABLE E-9-8 CONTINUED

SYST F	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
4-908 Ton AB Chillers	371,200	11,155		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,215,386	120,399	920,747	1,285,215
Bldg Equip	964,699	20,880		
Total	3,180,085	141,279	920,747	1,413,193
* SYST G				
9-DDA 795 KW D	1,570,523	105,307	890,305	
4-908 Ton AB Chillers	371,200	11,155		
Pumps	85,286	935		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,192,009	120,397	890,305	1,252,196
Bldg Equip	964,699	20,880		
Total	3,156,708	141,277	890,305	1,380,174
Ducts & Piping	371,693	0		
Air Handling Units	547,592	20,880		
Mech Room Substation	45,414	0		
Total	964,699	20,880		127,978

* Best Total Energy System, 60 Foot Building - 50 Acres

APPENDIX E-10

INTERNAL ENERGY SYSTEMS SELECTION-SENSITIVITY ANALYSIS COST DATA

In order to check the sensitivity of energy system selection to changes in operating hours, a cost analysis was conducted by increasing the facility operating hours to a full work shift 16 hours a day five days a week plus a single eight hour shift on Saturdays, Sundays, and holidays. This analysis was also conducted for a 24 hour a day full shift work schedule on every day of the year. Systems studied included the selected purchased power system for each building height, the best gas turbine sets, the best gas turbine/steam turbine sets, and the best diesel generator total energy sets. Tables in this appendix show the cost results for each system evaluated. The study showed that cost differentials remained constant for the intermediate level of operation and were only slightly reduced for the 24 hour a day level of operation.

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TABLE E-10-1

30 FOOT BUILDING, 24 HOUR OPERATION

* SYST 1 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-525 Ton & 2-950 Ton	312,800	19,878	173,909	
Pumps	60,849	770		
Cooling Tower	86,000	2,000		
Sub Total	459,649	22,648	173,909	247,197
Bldg Equip	1,887,437	17,215	2,260,901	
Total	2,806,735	39,863	2,434,810	2,733,252
SYST 2				
8-Solar 1200 KW GT/ST	2,240,000	138,028	2,502,652	
Open Chillers 2-525 Ton & 2-950 Ton	312,800	19,878		
Pumps	60,849	770		
Cooling Tower	86,000	2,000		
Sub Total	2,699,649	160,678	2,502,652	2,960,750
Bldg Equip	840,970	14,570		
Total	6,240,268	335,924	2,502,652	3,061,970
SYST 3				
4-DDA 3000 KW GT	2,376,000	78,783	3,112,086	
3-1148 Ton AB Chillers	339,600	26,095		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		

* Best 24 Hour Operation System, 30 Foot Building

TABLE E-10-1 CONTINUED

SYST 3	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Waste Boilers				
Sub Total	2,948,150	108,593	3,112,086	3,545,477
Bldg Equip	840,970	14,570		
Total	3,789,120	123,163	3,112,086	3,652,697
SYST 4				
11-DDA 795 KW D	1,919,528	289,172	2,228,936	
3-1148 Ton AB Chillers	339,600	26,095		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,491,678	318,982	2,228,936	2,822,426
Bldg Equip	840,970	14,570		
Total	3,332,648	333,552	2,228,936	2,929,646
Bldg Equip - Elec				
Bldg Elec Cost			2,260,901	
Boiler System	18,513	0		
Air Handling Units	320,334	10,640		
Ducts & Piping	238,374	0		
Fans	236,848	3,930		
Backup Power	872,513	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,887,437	17,215	2,260,901	2,486,055

TABLE E-10-1 CONTINUED

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip - TE				
Ducts & Piping	238,374	0		
Air Handling Units	320,334	10,640		
Fans	236,848	3,930		
Mech Room Substation	45,414	0		
Total	840,970	14,570		107,220

TABLE E-10-2

40 FOOT BUILDING, 24 HOUR OPERATION

* SYST 1 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
1-400 Ton & 3-725 Ton	284,300	19,239	148,034	
Pumps	57,389	770		
Cooling Tower	76,000	2,000		
Sub Total	417,689	22,009	148,034	216,060
Bldg Equip	1,836,528	15,305	2,016,198	
Total	2,254,217	37,314	2,164,232	2,449,893
SYST 2				
7-Solar 1200 KW GT/ST	1,960,000	122,689	2,236,020	
Open Chillers 1-400 Ton & 3-725 Ton	284,300	19,239		
Pumps	57,389	770		
Cooling Tower	76,000	2,000		
Sub Total	2,391,558	144,698	2,236,020	2,644,196
Bldg Equip	789,451	12,660		
Total	3,181,009	157,298	2,236,020	2,743,830
SYST 3				
4-DDA 3000 KW GT	2,376,000	70,213	2,596,297	
3-960 Ton AB Chillers	290,700	22,742		
Pumps	66,348	715		
Cooling Tower	140,000	3,000		

* Best 24 Hour Operation System, 40 Foot Building

TABLE E-10-2 CONTINUED

SYST 3	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Waste Boilers				
Sub Total	2,873,048	96,670	2,596,297	3,009,491
Bldg Equip	789,451	12,660		
Total	3,662,499	109,270	2,596,297	3,109,125
SYST 4				
10-DDA 795 KW D	1,745,025	257,683	1,966,997	
3-960 Ton AB Chillers	290,700	22,742		
Pumps	66,348	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,242,073	284,141	1,966,997	2,498,147
Bldg Equip	789,451	12,660		
Total	3,031,524	296,801	1,966,997	2,597,781
Bldg Equip - Elec				
Bldg Elec Cost			2,016,198	
Boiler System	22,236	0		
Air Handling Units	276,348	9,360		
Ducts & Piping	224,259	0		
Fans	243,430	3,300		
Backup Power	869,400	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,836,528	15,305	2,016,198	2,233,833

TABLE E-10-2 CONTINUED

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip - TE				
Ducts & Piping	224,259	0		
Air Handling Units	276,348	9,360		
Fans	243,430	3,300		
Mech Room Substation	45,414	0		
Total	789,451	12,660		99,634

TABLE E-10-3

50 FOOT BUILDING, 24 HOUR OPERATION

SYST 1 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-950 Ton	296,000	15,962	115,539	
Pumps	58,316	770		
Cooling Tower	76,000	2,000		
Sub Total	430,316	18,732	115,539	181,679
Bldg Equip	1,878,934	16,555	1,932,454	
Total	2,309,950	35,287	2,047,993	2,784,804
SYST 2				
7-Solar 1200 KW GT/ST	1,960,000	116,099	2,126,198	
Open Chillers 2-400 Ton & 2-950 Ton	296,000	15,962		
Pumps	58,316	770		
Cooling Tower	76,000	2,000		
Sub Total	2,390,316	134,831	2,126,198	2,524,370
Bldg Equip	831,857	16,555		
Total	3,222,173	151,386	2,126,198	2,632,571
SYST 3				
3-DDA 3000 KW GT	1,782,000	67,122	2,479,540	
3-908 Ton AB Chillers	278,400	20,153		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,265,349	90,990	2,479,540	2,820,103

TABLE E-10-3 CONTINUED

SYST 3	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip	831,857	16,555		
Total	2,097,206	107,545	2,479,540	2,928,304
* SYST 4				
10-DDA 795 KW D	1,745,025	246,319	1,872,988	
3-908 Ton AB Chillers	278,400	20,153		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,228,374	270,187	1,872,988	2,388,675
Bldg Equip	831,857	13,910		
Total	3,060,231	284,097	1,872,988	2,494,231
Bldg Equip - Elec				
Bldg Elec Cost			1,932,454	
Boiler System	22,236	0		
Air Handling Units	287,438	10,640		
Ducts & Piping	221,055	0		
Fans	277,950	3,270		
Backup Power	869,400	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,878,934	16,555	1,932,454	2,603,125

* Best 24 Hour Operation System, 50 Foot Building

TABLE E-10-3 CONTINUED

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip - TE				
Ducts & Piping	221,055	0		
Air Handling Units	287,438	10,640		
Fans	277,950	3,270		
Mech Room Substation	45,414	0		
Total	831,857	13,910		105,556

TABLE E-10-4

60 FOOT BUILDING, 24 HOUR OPERATION

* SYST 1 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-950 Ton	296,000	14,416	104,182	
Pumps	58,558	770		
Cooling Tower	77,000	2,000		
Sub Total	431,558	17,186	104,182	168,913
Bldg Equip	1,810,050	18,495	1,847.016	
Total	2,241,608	35,681	1,951,198	2,233,837
SYST 2				
7-Solar 1200 KW GT/ST	1,960,000	110,612	2,015,040	
Open Chillers 2-400 Ton & 2-950 Ton	296,000	14,416		
Pumps	58,558	770		
Cooling Tower	77,000	2,000		
Sub Total	2,391,558	127,798	2,015,040	2,406,316
Bldg Equip	926,264	15,850		
Total	3,317,822	143,648	2,015,040	2,524,997
SYST 3				
3-DDA 3000 KW GT	1,782,000	64,039	2,403,786	
3-908 Ton AB Chillers	278,400	17,514		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		

* Best 24 Hour Operation System, 60 Foot Building

TABLE E-10-4 CONTINUED

SYST 3	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Waste Boilers				
Sub Total	2,265,349	85,268	2,403,786	2,738,627
Bldg Equip	926,264	15,850		
Total	3,191,613	101,118	2,403,786	2,857,308
SYST 4				
9-DDA 795 KW D	1,570,522	234,995	1,780,211	
3-908 Ton AB Chillers	278,400	17,514		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,053,871	256,224	1,780,211	2,262,710
Bldg Equip	926,264	15,850		
Total	2,980,135	272,074	1,780,211	2,381,391
Bldg Equip - Elec				
Bldg Elec Costs			1,847,016	
Boiler System	30,335	0		
Air Handling Units	314,800	11,920		
Ducts & Piping	232,000	0		
Fans	334,050	3,930		
Backup Power	698,010	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,810,050	18,495	1,847,016	2,064,924

TABLE E-10-4 CONTINUED

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip - TE				
Ducts & Piping	232,000	0		
Air Handling Units	314,800	11,920		
Fans	334,050	3,930		
Mech Room Substation	45,414	0		
Total	926,268	15,850		118,681

TABLE E-10-5

30 FOOT BUILDING, 16 HOUR OPERATION

* SYST 1 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-525 Ton & 2-950 Ton	312,800	11,669	101,885	
Pumps	60,849	770		
Cooling Tower	86,000	2,000		
Sub Total	459,649	14,439	101,885	166,964
Bldg Equip	1,887,437	17,215	1,307,989	
Total	2,806,735	31,654	1,409,874	1,700,107
SYST 2				
8-Solar 1200 KW GT/ST	2,240,000	79,925	1,482,772	
Open Chillers 2-525 Ton & 2-950 Ton	312,800	11,669		
Pumps	60,849	770		
Cooling Tower	86,000	2,000		
Sub Total	2,699,649	94,364	1,482,772	1,874,556
Bldg Equip	840,970	14,570		
Total	6,240,268	108,934	1,482,772	1,981,776
SYST 3				
4-DDA 3000 KW GT	2,376,000	45,562	1,945,169	
3-1148 Ton AB Chillers	339,600	14,776		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		

* Best 16 Hour Operation System, 30 Foot Building

TABLE E-10-5 CONTINUED

SYST 3	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Waste Boilers				
Sub Total	2,948,150	64,053	1,945,169	2,334,020
Bldg Equip	840,970	14,570		
Total	3,789,120	78,623	1,945,169	2,441,240
SYST 4				
11-DDA 795 KW D	1,919,528	167,248	1,319,607	
3-1148 Ton AB Chillers	339,600	14,776		
Pumps	67,550	715		
Cooling Tower	165,000	3,000		
Waste Boilers				
Sub Total	2,491,678	185,739	1,319,607	1,779,854
Bldg Equip	840,970	14,570		
Total	3,332,648	200,309	1,319,607	1,887,074
Bldg Equip - Elec				
Bldg Elec Costs			1,307,989	
Boiler System	18,513	0		
Air Handling Units	320,334	10,640		
Ducts & Piping	238,374	0		
Fans	236,848	3,930		
Backup Power	872,513	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,887,437	17,215	1,307,989	1,533,143

TABLE E-10-5 CONTINUED

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip - TE				
Ducts & Piping	238,374	0		
Air Handling Units	320,334	10,640		
Fans	236,848	3,930		
Mech Room Substation	45,414	0		
Total	840,970	14,570		107,220

TABLE E-10-6

40 FOOT BUILDING, 16 HOUR OPERATION

* SYST 1 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
1-400 Ton & 3-725 Ton	284,300	9,979	90,302	
Pumps	57,389	770		
Cooling Tower	76,000	2,000		
Sub Total	417,689	12,749	90,302	149,068
Bldg Equip	1,836,528	15,305	1,177,136	
Total	2,254,217	28,054	1,267,438	1,543,839
SYST 2				
7-Solar 1200 KW GT/ST	1,960,000	71,850	1,345,618	
Open Chillers 1-400 Ton & 3-725 Ton	284,300	9,979		
Pumps	57,389	770		
Cooling Tower	76,000	2,000		
Sub Total	2,377,689	84,599	1,345,618	1,692,167
Bldg Equip	789,451	12,660		
Total	3,167,140	97,259	1,345,618	1,791,801
SYST 3				
3-DDA 3000 KW GT	1,782,000	41,001	1,694,929	
3-960 Ton AB Chillers	290,700	13,196		
Pumps	66,348	715		
Cooling Tower	140,000	3,000		

* Best 16 Hour Operation System, 40 Foot Building

TABLE E-10-6 CONTINUED

SYST 3	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Waste Boilers				
Sub Total	2,279,048	57,912	1,694,929	2,003,924
Bldg Equip	789,451	12,660		
Total	3,068,499	70,572	1,694,929	2,103,556
SYST 4				
10-DDA 795 KW D	1,745,025	150,486	1,179,837	
3-960 Ton AB Chillers	290,700	13,196		
Pumps	66,348	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,242,073	167,397	1,179,837	1,594,243
Bldg Equip	789,451	12,660		
Total	3,031,524	180,057	1,179,837	1,693,877
Bldg Equip - Elec				
Bldg Elec Costs			1,177,136	
Boiler System	22,236	0		
Air Handling Units	276,348	9,360		
Ducts & Piping	224,259	0		
Fans	243,430	3,300		
Backup Power	869,400	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,836,528	15,305	1,177,136	1,394,771

TABLE E-10-6 CONTINUED

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip - TE				
Ducts & Piping	224,259	0		
Air Handling Units	276,348	9,360		
Fans	243,430	3,300		
Mech Room Substation	45,414	0		
Total	789,451	12,660		99,634

TABLE E-10-7

50 FOOT BUILDING, 16 HOUR OPERATION

* SYST 1 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-950 Ton	296,000	9,509	72,078	
Pumps	58,316	770		
Cooling Tower	76,000	2,000		
Sub Total	430,316	12,279	72,078	132,129
Bldg Equip	1,878,934	16,555	1,131,191	
Total	2,309,250	28,834	1,203,269	1,488,469
SYST 2				
7-Solar 1200 KW GT/ST	1,960,000	68,212	1,276,629	
Open Chillers 2-400 Ton & 2-950 Ton	296,000	9,509		
Pumps	58,316	770		
Cooling Tower	76,000	2,000		
Sub Total	2,390,316	80,491	1,276,629	1,622,485
Bldg Equip	831,857	13,910		
Total	3,222,173	94,401	1,276,629	1,728,745
SYST 3				
3-DDA 3000 KW GT	1,782,000	39,297	1,619,643	
3-908 Ton AB Chillers	278,400	11,623		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		

* Best 16 Hour Operation System, 50 Foot Building

TABLE E-10-7 CONTINUED

SYST 3	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Waste Boilers				
Sub Total	2,265,349	54,635	1,619,643	1,925,770
Bldg Equip	831,857	13,910		
Total	3,097,206	68,545	1,619,643	2,032,030
SYST 4				
10-DDA 795 KW D	1,745,025	144,221	1,125,311	
3-908 Ton AB Chillers	278,400	11,635		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,228,374	159,571	1,125,311	1,532,269
Bldg Equip	831,857	13,910		
Total	3,060,231	173,481	1,125,311	1,638,529
Bldg Equip - Elec				
Bldg Elec Costs			1,131,191	
Boiler System	22,236	0		
Air Handling Units	287,438	10,640		
Ducts & Piping	221,055	0		
Fans	277,950	3,270		
Backup Power	869,400	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,878,934	16,555	1,131,191	1,356,340

TABLE E-10-7 CONTINUED

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip - TE				
Ducts & Piping	221,055	0		
Air Handling Units	287,438	10,640		
Fans	277,950	3,270		
Mech Room Substation	45,414	0		
Total	831,857	13,910		106,260

TABLE E-10-8

60 FOOT BUILDING, 16 HOUR OPERATION

* SYST 1 OPEN	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
2-400 Ton & 2-950 Ton	296,000	8,615	64,713	
Pumps	58,558	770		
Cooling Tower	77,000	2,000		
Sub Total	431,558	11,385	64,713	123,643
Bldg Equip	1,810,050	18,495	1,083,535	
Total	2,241,608	29,880	1,148,248	1,426,619
SYST 2				
7-Solar 1200 KW GT/ST	1,960,000	65,093	1,215,283	
Open Chillers 2-400 Ton & 2-950 Ton	296,000	8,615		
Pumps	58,558	770		
Cooling Tower	77,000	2,000		
Sub Total	2,391,558	76,478	1,215,283	1,555,239
Bldg Equip	926,264	15,850		
Total	3,317,822	92,328	1,215,283	1,673,920
SYST 3				
3-DDA 3000 KW GT	1,782,000	37,605	1,578,079	
3-908 Ton AB Chillers	278,400	10,665		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		

* Best 16 Hour Operation System, 60 Foot Building

TABLE E-10-8 CONTINUED

SYST 3	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Waste Boilers				
Sub Total	2,265,349	51,985	1,578,079	1,879,638
Bldg Equip	926,264	15,850		
Total	3,191,613	67,835	1,578,079	1,998,319
SYST 4				
9-DDA 795 KW D	1,570,522	138,010	1,073,696	
3-908 Ton AB Chillers	278,400	10,665		
Pumps	64,949	715		
Cooling Tower	140,000	3,000		
Waste Boilers				
Sub Total	2,053,871	152,390	1,073,696	1,452,361
Bldg Equip	926,264	15,850		
Total	2,980,135	168,240	1,073,696	1,571,042
Bldg Equip - Elec				
Bldg Elec Costs			1,083,535	
Boiler System	30,335	0		
Air Handling Units	314,800	11,920		
Ducts & Piping	232,000	0		
Fans	334,050	3,930		
Backup Power	698,010	0		
Emergency Batteries	93,428	2,645		
Mech Room Substation	107,427	0		
Total	1,810,050	18,495	1,083,535	1,302,976

TABLE E-10-8 CONTINUED

	CAPITAL	MAINT	ENERGY	ANNUAL COSTS
Bldg Equip - TE				
Ducts & Piping	232,000	0		
Air Handling Units	314,800	11,920		
Fans	334,050	3,930		
Mech Room Substation	45,414	0		
Total	926,264	15,850		118,681

Solar Energy Systems Appendix Symbols

CN - Clearness number

COP - Coefficient of performance

I - Insolation

Langley - 3.688 BTU per sq ft

MBTU - 1000 BTU's

Q - Energy available from collectors

TA - Mean daylight ambient temperature

TE - Fluid exit temperature

TI - Fluid inlet temperature

TM - Mean collector temperature

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APPENDIX E-11

SOLAR ENERGY SYSTEMS

The following sample calculations are for the two solar collection methods analyzed in this study. Due to the inconsistency of insolation data available from several sources for the Norfolk, Virginia area, representative insolation values were used for all calculations. All cooling data was extracted from the ECUBE energy requirements printout.

Design Analysis. The first solar collection method utilizes automatic tracking collectors. System 2 for the 30 foot building is presented.

Given:

975 tons provided by absorption chillers X 1.82 increase factor for 200° water solution (1775 tons installed capacity minimum)

963 tons provided by electric centrifugal chillers (963 tons installed capacity minimum)

Electric chillers:

2-559 ton units installed as the primary units

1-559 ton unit installed as the backup unit

Capital cost	= $153,698
Starting units cost	= $ 14,400
Installation cost	= $ 15,370
Annual maintenance cost	= $ 17,888
Annual electricity cost	= $ 47,710
Total annual cost	= $ 85,810

Absorption chillers:

2-955 ton units installed as the primary units

Capital cost = $188,486

Installation cost = $ 18,849

Annual maintenance cost = $ 19,100

Total annual cost = $ 41,943

Solar equipment:

TM = (TI + TE)/2 = (180°F + 200°F/2 = 190°F

TA = 70° (approximated, based on ECUBE weather tape average for May, Washington, D.C.)

CN = .95

TM - TA = 120°F

I = 1600 BTU/sq ft-day) (Northrup, 1976)

(2,174,991,000 BTU/mo)/(31 days/mo) = 70,161,000 BTU/day (peak cooling load for May)

(70,161,000 BTU/day)/(1600 BTU/sq ft-day = 43,851 sq ft of collectors required

Capital cost = $18/sq ft X 43,851 sq ft = $789,311

Installation cost = $157,862

Antifreeze cost = $ 43,851

Pumps, piping, etc. = $ 87,702

Annual maintenance cost = $ 10,787

Total annual cost = $129,630

Total system annual cost for system 2, 30 foot building = $257,383

The second solar collection method utilizes flat plate collectors. System 2 for the 30 foot building is presented.

Given:

1775 tons installed capacity of absorption chillers

963 tons installed capacity of electric centrifugal chillers

Electric chillers:

Total annual cost = $85,810

Absorption chillers:

Total annual cost = $41,943

Solar equipment:

(70,161,000 BTU/day)/(24 hr/day) = 2,923,375 BTU/hr required

COP = 0.6 = (2,923,375 BTU/hr)/BTU supplied

BTU supplied by solar = 4,872,292 BTU/hr

I = (3.688 BTU/sq ft-langley)(540 langleys/day) = 1992 BTU/sq ft-day (Beck and Field, 1976)

Q = (1992 BTU/sq ft)(0.5)(0.67)(31 days/mo)(1 sq ft) = 20,687 BTU/mo-sq ft

(20,687 BTU/mo-sq ft)/(744 hr/mo) = 28 BTU/hr-sq ft from collectors = (4,872,292 BTU/hr)/(28 BTU/hr-sq ft) = 174,010 sq ft of collectors required

Capital cost = $8/sq ft X 174,010 sq ft	= $1,392,080
Installation cost	= $ 278,416
Antifreeze cost	= $ 348,020
Pumps, piping, etc.	= $ 174,010
Annual maintenance cost	= $ 21,925
Total annual cost	= $ 263,475

Total system annual cost for system 2, 30 foot building = $391,228

APPENDIX E-12

EQUIPMENT SELECTION AND ENERGY CONSUMPTION DATA

This appendix contains the ECUBE computer simulation output for each of the equipment selection runs made during the GCE-76S study. This information is included here as a reference to the data base needed to compute the equipment maintenance costs and the diesel oil or electrical purchase requirements necessary for evaluating each of the building energy systems investigated during the study. This data is divided into four sections. The first section contains the output for purchased power systems. The second section contains the equivalent data for total energy systems. The third section includes the output data associated with the evaluation of commercial power versus total energy cost differentials as the facility operating hours were changed. The final section contains equipment selection data for alternative geographic sites including Harrisburg, Pennsylvania; Oklahoma City, Oklahoma; Los Angeles, California; and Oakland, California.

Commercial Power Systems Data

Information presented in this section of the appendix covers the facility electrical consumption and the centrifugal chiller operating hours associated with each of the systems described in the "Commercial Power Systems" section of this report. Pages E-12-3 through E-12-6 cover the eight centrifugal chiller systems associated with the 30 foot building. Pages E-12-7 through E-12-10, E-12-11 through E-12-14, and E-12-15 through E-12-18 contain similar data for the 40, 50, and 60 foot buildings, respectively.

30 FOOT BUILDING PURCHASED POWER HERMETIC CHILLER SYSTEMS 1 AND 2
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG E1 HERMETIC ELECT. CHILLERS SYSTS. 1 AND 2

** TOTAL **

SYSTEM E1 TWO-800 TON, ONE-400 TON
SYSTEM E2 TWO-950 TON, TWO-525 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.
ELECTRICAL CONSUMPTION, KWH	24499854.	24359303.
PEAK KW DEMAND (60 MIN BASIS)	7804.	7798.
AUXILIARY FUEL CONSUMPTION	0.	0.
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.
CHILLER OPERATING HOURS		
CHILLER 1	1235	3152
CHILLER 2	2072	1511
CHILLER 3	1105	329
CHILLER 4	0	0
RECOVERABLE HEAT USED, MBTU	0.	0.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.

COPY AVAILABLE TO DDC DOES NOT PERMIT FULLY LEGIBLE PRODUCTION

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30 FOOT BUILDING PURCHASED POWER HERMETIC CHILLER SYSTEMS 3 AND 4

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. E1 HERMETIC ELECT. CHILLERS SYSTS. 3AND 4

SYSTEM E1 THREE-1050 TON
SYSTEM E2 FOUR-675 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	24551217.	24620908.	
PEAK KW DEMAND (60 MIN BASIS)	7746.	7879.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	3020	3111	
CHILLER 2	732	1331	
CHILLER 3	0	409	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	

30 FOOT BUILDING PURCHASED POWER OPEN CHILLER SYSTEMS 1 AND 2
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG 31 OPEN C ELECT. CHILLERS SYSTS. 1 AND 2

** TOTAL **

SYSTEM E1 TWO-800 TON, ONE-400 TON
SYSTEM E2 TWO-950 TON, TWO-525 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.
ELECTRICAL CONSUMPTION, KWH	24368884.	24277989.
PEAK KW DEMAND (60 MIN BASIS)	7686.	7702.
AUXILIARY FUEL CONSUMPTION	0.	0.
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.
CHILLER OPERATING HOURS		
CHILLER 1	1235	3152
CHILLER 2	2072	1511
CHILLER 3	1105	329
CHILLER 4	0	0
RECOVERABLE HEAT USED, MBTU	0.	0.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.

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30 FOOT BUILDING PURCHASED POWER OPEN CHILLER SYSTEMS 3 AND 4
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. #1 OPEN ELECT. CHILLERS SYSTS. 3AND 4

SYSTEM E1 THREE-1050 TON
SYSTEM E2 FOUR-675 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	24416462.	24455364.	
PEAK KW DEMAND (60 MIN BASIS)	7627.	7728.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	3020	3111	
CHILLER 2	732	1331	
CHILLER 3	0	409	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU		0.	

40 FOOT BUILDING PURCHASED POWER HERMETIC CHILLER SYSTEMS 1 AND 2
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. #2 HERMETIC ELEC. CHILLERS SYSTS. 1 AND 2

SYSTEM E1 TWO-725 TON, ONE-400 TON
SYSTEM E2 TWO-1050 TON, TWO-400 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	22062200.	22060847.	
PEAK KW DEMAND (60 MIN BASIS)	7024.	6973.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	1314	2916	
CHILLER 2	1712	1712	
CHILLER 3	997	736	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	

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40 FOOT BUILDING PURCHASED POWER HERMETIC CHILLER SYSTEMS 3 AND 4
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. 52 HERMETIC ELEC. CHILLERS SYSTS, 3 AND 4

SYSTEM E1 THREE-950 TON
SYSTEM E2 FOUR-620 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	22061138.	22138365.	
PEAK KW DEMAND (60 MIN BASIS)	6941.	7078.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	2733	2837	
CHILLER 2	673	1174	
CHILLER 3	0	372	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	

40 FOOT BUILDING PURCHASED POWER OPEN CHILLER SYSTEMS 1 AND 2
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. 32 OPEN ELEC. CHILLERS SYSTS. 1 AND 2

** TOTAL **

SYSTEM E1 TWO-725 TON, ONE-400 TON
SYSTEM E2 TWO-1050 TON, TWO-400 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.
ELECTRICAL CONSUMPTION, KWH	21947615.	21979352.
PEAK KW DEMAND (60 MIN BASIS)	6908.	6877.
AUXILIARY FUEL CONSUMPTION	0.	0.
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.
CHILLER OPERATING HOURS		
CHILLER 1	1314	2916
CHILLER 2	1712	1712
CHILLER 3	997	736
CHILLER 4	0	0
RECOVERABLE HEAT USED, MBTU	0.	0.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.

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40 FOOT BUILDING PURCHASED POWER OPEN CHILLER SYSTEMS 3 AND 4
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. #2 OPEN ELEC. CHILLERS SYSTS. 3 AND 4

SYSTEM E1 THREE-950 TON
SYSTEM E2 FOUR-620 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	21951516.	22045793.	
PEAK KW DEMAND (60 MIN BASIS)	6831.	6983.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	2733	2837	
CHILLER 2	673	1174	
CHILLER 3	0	372	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	

50 FOOT BUILDING PURCHASED POWER HERMETIC CHILLER SYSTEMS 1 AND 2
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. 3 HERMETIC ELEC. CHILLERS SYSTS. 1 AND2

** TOTAL **

SYSTEM E1 TWO-675 TON, ONE-400 TON
SYSTEM E2 TWO-950 TON, TWO-433 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.
ELECTRICAL CONSUMPTION, KWH	21024620.	20859513.
PEAK KW DEMAND (60 MIN BASIS)	6613.	6596.
AUXILIARY FUEL CONSUMPTION	0.	0.
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.
CHILLER OPERATING HOURS		
CHILLER 1	1317	2759
CHILLER 2	1561	1308
CHILLER 3	994	351
CHILLER 4	0	0
RECOVERABLE HEAT USED, MBTU	0.	0.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.

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50 FOOT BUILDING PURCHASED POWER HERMETIC CHILLER SYSTEMS 3 AND 4
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. 33 HERNETIC ELEC. CHILLERS SYSTS. 3 AND 4

** TOTAL **

SYSTEM E1 THREE-950 TON
SYSTEM E2 FOUR-575 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.
ELECTRICAL CONSUMPTION, KWH	21212710.	21050926.
PEAK KW DEMAND (60 MIN BASIS)	6747.	6618.
AUXILIARY FUEL CONSUMPTION	0.	0.
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.
CHILLER OPERATING HOURS		
CHILLER 1	2607	2696
CHILLER 2	722	1129
CHILLER 3	1	390
CHILLER 4	0	0
RECOVERABLE HEAT USED, MBTU	0.	0.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.

50 FOOT BUILDING PURCHASED POWER OPEN CHILLER SYSTEMS 1 AND 2
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. #3 OPEN ELEC. CHILLERS SYSTS. 1 AND2

SYSTEM E1 TWO-675 TON, ONE-400 TON
SYSTEM E2 TWO-950 TON, TWO-433 TON

** TOTAL **

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.
ELECTRICAL CONSUMPTION, KWH	20911010.	20797000.
PEAK KW DEMAND (60 MIN BASIS)	6492.	6505.
AUXILIARY FUEL CONSUMPTION	0.	0.
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.
CHILLER OPERATING HOURS		
CHILLER 1	1317	2759
CHILLER 2	1561	1308
CHILLER 3	994	351
CHILLER 4	0	0
RECOVERABLE HEAT USED, MBTU	0.	0.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.

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50 FOOT BUILDING PURCHASED POWER OPEN CHILLER SYSTEMS 3 AND 4
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. 3 OPEN ELEC. CHILLERS SYSTS. 3 AND 4

SYSTEM E1 THREE-950 TON
SYSTEM E2 FOUR-575 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	21102189.	20998975.	
PEAK KW DEMAND (60 MIN BASIS)	6632.	6561.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	2607	2696	
CHILLER 2	722	1129	
CHILLER 3	1	390	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	

60 FOOT BUILDING PURCHASED POWER HERMETIC CHILLER SYSTEMS 1 AND 2
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG E4 HERMETIC ELEC. CHILLERS SYSTS. 1 AND 2

SYSTEM E1 ONE-350 TON, TWO-675 TON
SYSTEM E2 TWO-400 TON, TWO-950 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	19947397.	19763855.	
PEAK KW DEMAND (60 MIN BASIS)	6287.	6240.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	1099	2588	
CHILLER 2	1585	1210	
CHILLER 3	914	265	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	

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60 FOOT BUILDING PURCHASED POWER HERMETIC CHILLER SYSTEMS 3 AND 4
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. 64 HEMETIC ELEC. CHILLERS SYSTS. 3 AND 4

SYSTEM E1 THREE-850 TON
SYSTEM E2 FOUR-575 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	19967579.	19924931.	
PEAK KW DEMAND (60 MIN BASIS)	6222.	6239.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	2449	2529	
CHILLER 2	643	1069	
CHILLER 3	0	309	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	

60 FOOT BUILDING PURCHASED POWER OPEN CHILLER SYSTEMS 1 AND 2
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG 34 OPEN ELEC. CHILLERS SYSTS. 1 AND 2

** TOTAL **

SYSTEM E1 ONE-350 TON, TWO-675 TON
SYSTEM E2 TWO-400 TON, TWO-950 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.
ELECTRICAL CONSUMPTION, KWH	19840683.	19708006.
PEAK KW DEMAND (60 MIN BASIS)	6165.	6153.
AUXILIARY FUEL CONSUMPTION	0.	0.
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.
CHILLER OPERATING HOURS		
CHILLER 1	1099	2588
CHILLER 2	1585	1210
CHILLER 3	914	265
CHILLER 4	0	0
RECOVERABLE HEAT USED, MBTU	0.	0.
RECOVERABLE HEAT UNUSED, MBTU	24246.	29535.

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60 FOOT BUILDING PURCHASED POWER OPEN CHILLERS SYSTEMS 3 AND 4
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BLDG. E4 OPEN - ELEC. CHILLERS SYSTS. 3 AND 4

SYSTEM E1 THREE-850 TON
SYSTEM E2 FOUR-575 TON

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM E2	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	
ELECTRICAL CONSUMPTION, KWH	19883837.	19877598.	
PEAK KW DEMAND (60 MIN BASIS)	6126.	6184.	
AUXILIARY FUEL CONSUMPTION	0.	0.	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	
CHILLER OPERATING HOURS			
CHILLER 1	2449	2529	
CHILLER 2	643	1069	
CHILLER 3	0	309	
CHILLER 4	0	0	
RECOVERABLE HEAT USED, MBTU	0.	0.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	

Total Energy Systems Data

Information included in this section of the appendix includes the diesel oil fuel requirements, the generator operating hours, the chiller operating hours, and the waste heat recovery values for each of the systems discussed in the "Total Energy Systems" section of this report. Recoverable heat used values represent the heat reclaimed by the absorption chillers to meet facility air conditioning needs. The difference in recoverable heat values shown for gas turbine generator systems and diesel generator systems represents the supplemental boiler loads required by the diesel systems. Recoverable heat unused values represent the excess waste heat not required for heating or air conditioning. Waste heat values are not shown for gas turbine/steam turbine systems since all recoverable exhaust heat is used by the steam turbine to meet the facility electrical loads. Pages E-12-20 through E-12-27 include the output for each of the seven systems studied for each of the four building heights where the operating area was air-conditioned, the mechanized area was air-conditioned and humidity controlled, and the general storage area was only ventilated. Pages E-12-28 through E-12-35 include similar information for each of the facilities in which the entire facility was air-conditioned.

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30 FOOT BUILDING - TOTAL ENERGY SYSTEMS 1, 2, 3, AND 4 - 20 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #1 ABSORPTION-20 ACRES SYSTEM 1

** TOTAL **

SYSTEM A1 DDA 3000KW GT
SYSTEM A2 SOLAR 800KW GT
SYSTEM A3 SOLAR 1200KW GT/ST
SYSTEM A4 SOLAR 2500KW GT

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	23109828.	23109828.	24361263.	23109828.
PEAK KW DEMAND (60 MIN BASIS)	7027.	7027.	8448.	7027.
AUXILIARY FUEL CONSUMPTION	3220971. GAL	3428103. GAL	2339202. GAL	3673854. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	8760
GENERATOR 2	5042	5042	5042	5042
GENERATOR 3	1570	5042	5042	2259
GENERATOR 4	0	5042	3602	0
GENERATOR 5	0	5042	2265	0
GENERATOR 6	0	2334	1208	0
GENERATOR 7	0	2259	326	0
GENERATOR 8	0	1954	0	0
GENERATOR 9	0	336	0	0
GENERATOR 10	0	1	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2942	2942	3079	2942
CHILLER 2	581	581	1533	581
CHILLER 3	0	0	332	0
CHILLER 4	0	0	0	0
RECOVERABLE HEAT USED, MBTU	45519984.	45519984.	0.	45519984.
RECOVERABLE HEAT UNUSED, MBTU	201928644.	184700235.	0.	180007893.

30 FOOT BUILDING - TOTAL ENERGY SYSTEMS 5, 6, AND 7 - 20 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E1 DIESEL 20 ACRES

SYSTEM A5 SOLAR 3750KW GTOST
SYSTEM A6 CUMMINS 690KW DIES
SYSTEM A7 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A5	SYSTEM A6	SYSTEM A7 ** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	24361263.	23141013.	23140398.
PEAK KW DEMAND (60 MIN BASIS)	8448.	7027.	7027.
AUXILIARY FUEL CONSUMPTION	2549086. GAL	2171455. GAL	2091832. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.
ENGINE OPERATING HOURS			
GENERATOR 1	8760	8760	8760
GENERATOR 2	5042	5042	5042
GENERATOR 3	326	5042	5042
GENERATOR 4	0	5042	5042
GENERATOR 5	0	5042	5042
GENERATOR 6	0	3923	2368
GENERATOR 7	0	2260	2259
GENERATOR 8	0	2259	1819
GENERATOR 9	0	1839	163
GENERATOR 10	0	410	0
CHILLER OPERATING HOURS			
CHILLER 1	3079	2942	2942
CHILLER 2	1533	581	581
CHILLER 3	332	0	0
CHILLER 4	0	0	0
BOILER OPERATING HOURS			
BOILER 1	0	1773	1743
BOILER 2	0	306	295
RECOVERABLE HEAT USED, MBTU	0.	29282036.	29707514.
RECOVERABLE HEAT UNUSED, MBTU	0.	26717038.	28062283.

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40 FOOT BUILDING - TOTAL ENERGY SYSTEMS 1, 2, 3, AND 4 - 20 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #2 ABSORPTION-20 ACRES SYSTEM 1

SYSTEM A1 DDA 3000KW GT
SYSTEM A2 SOLAR 500KW GT
SYSTEM A3 SOLAR 1200KW GT/ST
SYSTEM A4 SOLAR 2500KW GT

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	** TOTAL ** SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	20931129.	20931129.	21948288.	20931129.
PEAK KW DEMAND (60 MIN BASIS)	6193.	6193.	7329.	6193.
AUXILIARY FUEL CONSUMPTION	2909317. GAL	3154642. GAL	2126264. GAL	3431724. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	8760
GENERATOR 2	5042	5042	5042	5042
GENERATOR 3	42	5042	5042	2259
GENERATOR 4	0	5042	2932	0
GENERATOR 5	0	5042	2259	0
GENERATOR 6	0	2259	469	0
GENERATOR 7	0	2259	3	0
GENERATOR 8	0	446	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2705	2705	1271	2705
CHILLER 2	660	660	1720	660
CHILLER 3	0	0	1003	0
RECOVERABLE HEAT USED, MBTU	37415911.	37415911.	0.	37415911.
RECOVERABLE HEAT UNUSED, MBTU	185864728.	174833837.	0.	175949074.

40 FOOT BUILDING - TOTAL ENERGY SYSTEMS 5, 6, AND 7 - 20 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E2 DIESEL 20 ACRES

SYSTEM A5 SOLAR 3750KW GTOST
SYSTEM A6 CUMMINS 690KW DIES
SYSTEM A7 ODA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A5	SYSTEM A6	SYSTEM A7	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	21948288.	20957154.	20955939.	
PEAK KW DEMAND (60 MIN BASIS)	7329.	6193.	6193.	
AUXILIARY FUEL CONSUMPTION	2364742. GAL	1954883. GAL	1885808. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	
GENERATOR 2	5042	5042	5042	
GENERATOR 3	3	5042	5042	
GENERATOR 4	0	5042	5042	
GENERATOR 5	0	5042	3695	
GENERATOR 6	0	2516	2259	
GENERATOR 7	0	2259	2259	
GENERATOR 8	0	2259	342	
GENERATOR 9	0	403	0	
GENERATOR 10	0	0	0	
CHILLER OPERATING HOURS				
CHILLER 1	1271	2705	2705	
CHILLER 2	1720	660	660	
CHILLER 3	1003	0	0	
BOILER OPERATING HOURS				
BOILER 1	0	1561	1493	
BOILER 2	0	174	161	
RECOVERABLE HEAT USED, MBTU	0.	23777630.	24198701.	
RECOVERABLE HEAT UNUSED, MBTU		2725B113.	28221286.	

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50 FOOT BUILDING - TOTAL ENERGY SYSTEMS 1, 2, 3, AND 4 - 20 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E3 ABSORPTION-20 ACRES SYSTEM 1

SYSTEM A1 ODA 3000KW GT
SYSTEM A2 SOLAR 800KW GT
SYSTEM A3 SOLAR 1200KW GT/ST
SYSTEM A4 SOLAR 2500KW GT

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	** TOTAL ** SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	19992482.	19992482.	20858842.	19992482.
PEAK KW DEMAND (60 MIN BASIS)	5689.	5689.	6822.	5689.
AUXILIARY FUEL CONSUMPTION	2834651. GAL	3000631. GAL	2025544. GAL	3417445. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	8760
GENERATOR 2	5042	5042	5042	5042
GENERATOR 3	0	5042	5042	2259
GENERATOR 4	0	5042	2530	0
GENERATOR 5	0	3570	1717	0
GENERATOR 6	0	2259	321	0
GENERATOR 7	0	2259	0	0
GENERATOR 8	0	4	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2572	2572	2732	2572
CHILLER 2	640	640	1308	640
CHILLER 3	0	0	352	0
CHILLER 4	0	0	0	0
RECOVERABLE HEAT USED, MBTU	33842218.	33842218.	0.	33842218.
RECOVERABLE HEAT UNUSED, MBTU	134230191.	167909716.	0.	174282639.

50 FOOT BUILDING - TOTAL ENERGY SYSTEMS 5, 6, AND 7 - 20 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E3 DIESEL 20 ACRES

SYSTEM A5 SOLAR 3750KW GTOST
SYSTEM A6 CUMMINS 690KW DIES
SYSTEM A7 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A5	SYSTEM A6	SYSTEM A7	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	20858842.	20015792.	20015177.	
PEAK KW DEMAND (60 MIN BASIS)	6822.	5689.	5689.	
AUXILIARY FUEL CONSUMPTION	2290601. GAL	1863818. GAL	1797584. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	
GENERATOR 2	5042	5042	5042	
GENERATOR 3	0	5042	5042	
GENERATOR 4	0	5042	5042	
GENERATOR 5	0	5042	3474	
GENERATOR 6	0	2357	2259	
GENERATOR 7	0	2259	2259	
GENERATOR 8	0	1274	3	
GENERATOR 9	0	3	0	
GENERATOR 10	0	0	0	
CHILLER OPERATING HOURS				
CHILLER 1	2732	2572	2572	
CHILLER 2	1308	640	640	
CHILLER 3	352	0	0	
CHILLER 4	0	0	0	
BOILER OPERATING HOURS				
BOILER 1	0	1417	1388	
BOILER 2	0	137	125	
RECOVERABLE HEAT USED, MBTU	0.	21407457.	21774048.	
RECOVERABLE HEAT UNUSED, MBTU	0.	27256014.	28357342.	

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60 FOOT BUILDING - TOTAL ENERGY SYSTEMS 1, 2, 3, AND 4 - 20 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #4 ABSORPTION-20 ACRES SYSTEM 1

SYSTEM A1 DDA 3000KW GT
SYSTEM A2 SOLAR 800KW GT
SYSTEM A3 SOLAR 1200KW GT/ST
SYSTEM A4 SOLAR 2500KW GT

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	18990651.	18990651.	19765889.	18990651.
PEAK KW DEMAND (60 MIN BASIS)	5235.	5235.	6241.	5235.
AUXILIARY FUEL CONSUMPTION	2759294. GAL	2833084. GAL	1922131. GAL	3175804. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	8760
GENERATOR 2	5042	5042	5042	5042
GENERATOR 3	0	5042	5042	821
GENERATOR 4	0	5042	2429	0
GENERATOR 5	0	2529	1064	0
GENERATOR 6	0	2259	68	0
GENERATOR 7	0	1164	0	0
GENERATOR 8	0	0	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2420	2420	2567	2420
CHILLER 2	582	582	1212	582
CHILLER 3	0	0	269	0
CHILLER 4	0	0	0	0
RECOVERABLE HEAT USED, MBTU	30880569.	30880569.	0.	30880569.
RECOVERABLE HEAT UNUSED, MBTU	131933621.	159338901.	0.	163174726.

60 FOOT BUILDING - TOTAL ENERGY SYSTEMS 5, 6, AND 7 - 20 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E4 DIESEL 20 ACRES

SYSTEM A5 SOLAR 3750KW GTOST
SYSTEM A6 CUMMINS 690KW DIES
SYSTEM A7 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A5	SYSTEM A6	SYSTEM A7	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	19765889.	19012266.	19011891.	
PEAK KW DEMAND (60 MIN BASIS)	6241.	5235.	5235.	
AUXILIARY FUEL CONSUMPTION	2123758. GAL	1768181. GAL	1707418. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	
GENERATOR 2	3586	5042	5042	
GENERATOR 3	0	5042	5042	
GENERATOR 4	0	5042	5042	
GENERATOR 5	0	5042	2432	
GENERATOR 6	0	2259	2259	
GENERATOR 7	0	2259	745	
GENERATOR 8	0	473	0	
GENERATOR 9	0	0	0	
GENERATOR 10	0	0	0	
CHILLER OPERATING HOURS				
CHILLER 1	2567	2420	2420	
CHILLER 2	1212	582	582	
CHILLER 3	269	0	0	
CHILLER 4	0	0	0	
BOILER OPERATING HOURS				
BOILER 1	0	1341	1326	
BOILER 2	0	100	90	
RECOVERABLE HEAT USED, MBTU	0.	19475119.	19692495.	
RECOVERABLE HEAT UNUSED, MBTU	0.	27102327.	24004253.	

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30 FOOT BUILDING - TOTAL ENERGY SYSTEMS 1, 2, 3, AND 4 - 50 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #1 ABSORPTION-50 ACRES SYSTEM 1

SYSTEM A1 DDA 3000KW GT
SYSTEM A2 SOLAR 800KW GT
SYSTEM A3 SOLAR 1200KW GT/ST
SYSTEM A4 SOLAR 2500KW GT

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP.. 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP.. 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION. KWH	23313894.	23288094.	24793488.	23389713.
PEAK KW DEMAND (60 MIN BASIS)	7271.	7271.	9030.	7548.
AUXILIARY FUEL CONSUMPTION	3234056. GAL	3455104. GAL	2269573. GAL	3687756. GAL
DIR. PROC. GAS CONSUMP.. 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	8760
GENERATOR 2	5042	5042	5042	5042
GENERATOR 3	1573	5042	5042	2259
GENERATOR 4	0	5042	3753	0
GENERATOR 5	0	5042	2453	0
GENERATOR 6	0	2567	0	0
GENERATOR 7	0	2259	0	0
GENERATOR 8	0	1456	0	0
GENERATOR 9	0	457	0	0
GENERATOR 10	0	4	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2988	2988	2992	2988
CHILLER 2	1115	1115	1128	1115
CHILLER 3	268	268	286	268
CHILLER 4	0	0	0	0
RECOVERABLE HEAT USED, MBTU	54696768.	54784923.	0.	54437998.
RECOVERABLE HEAT UNUSED, MBTU	194638577.	177256747.	0.	172039543.

30 FOOT BUILDING - TOTAL ENERGY SYSTEMS 5, 6, AND 7 - 50 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #1 DIESEL 50 ACRES

SYSTEM A5 SOLAR 3750KW GTGST
SYSTEM A6 CUMMINS 690KW DIES
SYSTEM A7 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A5	SYSTEM A6	SYSTEM A7 ** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	24793488.	23317438.	23316853.
PEAK KW DEMAND (60 MIN BASIS)	9030.	7271.	7271.
AUXILIARY FUEL CONSUMPTION	2583962. GAL	2271308. GAL	2190498. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.
ENGINE OPERATING HOURS			
GENERATOR 1	8760	8760	8760
GENERATOR 2	5042	5042	5042
GENERATOR 3	413	5042	5042
GENERATOR 4	0	5042	5042
GENERATOR 5	0	5042	5042
GENERATOR 6	0	3943	2498
GENERATOR 7	0	2309	2259
GENERATOR 8	0	2259	1817
GENERATOR 9	0	1852	294
GENERATOR 10	0	558	3
CHILLER OPERATING HOURS			
CHILLER 1	2992	2988	2988
CHILLER 2	1128	1115	1115
CHILLER 3	286	268	268
CHILLER 4	0	0	0
BOILER OPERATING HOURS			
BOILER 1	0	1818	1790
BOILER 2	0	682	671
RECOVERABLE HEAT USED, MBTU	0.	29526105.	30009820.
RECOVERABLE HEAT UNUSED, MBTU	0.	26857449.	28184310.

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40 FOOT BUILDING - TOTAL ENERGY SYSTEMS 1, 2, 3, AND 4 - 50 ACRES

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING 32 ABSORPTION-50 ACRES SYSTEM 1

SYSTEM A1 DDA 3000KW GT
SYSTEM A2 SOLAR 600KW GT
SYSTEM A3 SOLAR 1200KW GT/ST
SYSTEM A4 SOLAR 2500KW GT

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	** TOTAL ** SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	21050543.	21072537.	22286286.	21146046.
PEAK KW DEMAND (60 MIN BASIS)	6360.	6360.	7809.	7043.
AUXILIARY FUEL CONSUMPTION	2933290. GAL	3164663. GAL	2155579. GAL	3498433. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	8760
GENERATOR 2	5042	5042	5042	5042
GENERATOR 3	230	5042	5042	2259
GENERATOR 4	0	5042	3038	0
GENERATOR 5	0	5042	2291	0
GENERATOR 6	0	2259	565	0
GENERATOR 7	0	2259	0	0
GENERATOR 8	0	521	0	0
GENERATOR 9	0	2	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2720	2720	2728	2720
CHILLER 2	1018	1018	1059	1018
CHILLER 3	265	265	318	265
CHILLER 4	0	0	0	0
RECOVERABLE HEAT USED, MBTU	47658918.	47583854.	0.	47332988.
RECOVERABLE HEAT UNUSED, MBTU	177610011.	165329720.	0.	166461879.

40 FOOT BUILDING - TOTAL ENERGY SYSTEMS 5, 6, AND 7 - 50 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E2 DIESEL 50 ACRES

SYSTEM A5 SOLAR 3750KW GTOST
SYSTEM A6 CUMMINS 690KW DIES
SYSTEM A7 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A5	SYSTEM A6	SYSTEM A7	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	22282286.	21043393.	21042868.	
PEAK KW DEMAND (60 MIN BASIS)	7809.	6360.	6360.	
AUXILIARY FUEL CONSUMPTION	2390739. GAL	2057246. GAL	1988613. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	
GENERATOR 2	5042	5042	5042	
GENERATOR 3	51	5042	5042	
GENERATOR 4	0	5042	5042	
GENERATOR 5	0	5042	3706	
GENERATOR 6	0	2697	2259	
GENERATOR 7	0	2259	2259	
GENERATOR 8	0	2259	402	
GENERATOR 9	0	472	1	
GENERATOR 10	0	3	0	
CHILLER OPERATING HOURS				
CHILLER 1	2728	2720	2720	
CHILLER 2	1059	1018	1018	
CHILLER 3	318	265	265	
CHILLER 4	0	0	0	
BOILER OPERATING HOURS				
BOILER 1	0	1707	1674	
BOILER 2	0	644	642	
RECOVERABLE HEAT USED, MBTU	0.	24224949.	24658300.	
RECOVERABLE HEAT UNUSED, MBTU	0.	27089622.	27976542.	

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50 FOOT BUILDING - TOTAL ENERGY SYSTEMS 1, 2, 3, AND 4 - 50 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #3 ABSORPTION-50 ACRES SYSTEM 1

SYSTEM A1 DDA 3000KW GT
SYSTEM A2 SOLAR 800KW GT
SYSTEM A3 SOLAR 1200KW GT/ST
SYSTEM A4 SOLAR 2500KW GT

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	20219758.	20205907.	21342184.	20290036.
PEAK KW DEMAND (60 MIN BASIS)	7857.	6444.	7145.	7132.
AUXILIARY FUEL CONSUMPTION	2844926. GAL	3018537. GAL	2867216. GAL	3428220. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	8760
GENERATOR 2	5042	5042	5042	5042
GENERATOR 3	3	5042	5042	2259
GENERATOR 4	0	5042	2875	0
GENERATOR 5	0	3579	1705	0
GENERATOR 6	0	2259	391	0
GENERATOR 7	0	2259	0	0
GENERATOR 8	0	147	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2576	2576	2587	2576
CHILLER 2	1002	1002	1028	1002
CHILLER 3	252	252	295	252
CHILLER 4	0	0	0	0
RECOVERABLE HEAT USED, MBTU	45256144.	45303415.	0.	45016113.
RECOVERABLE HEAT UNUSED, MBTU	1735363R1.	1576504R2.	0.	1638498R6.

50 FOOT BUILDING - TOTAL ENERGY SYSTEMS 5, 6, AND 7 - 50 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E3 DIESEL 50 ACRES

SYSTEM A5 SOLAR 3750KW GTOST
SYSTEM A6 CUMMINS 690KW DIES
SYSTEM A7 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A5	SYSTEM A6	SYSTEM A7	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	21342184.	20159846.	20159441.	
PEAK KW DEMAND (60 MIN BASIS)	7145.	5884.	5884.	
AUXILIARY FUEL CONSUMPTION	2323473. GAL	1981630. GAL	1914440. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	
GENERATOR 2	5042	5042	5042	
GENERATOR 3	1	5042	5042	
GENERATOR 4	0	5042	5042	
GENERATOR 5	0	5042	3483	
GENERATOR 6	0	2543	2259	
GENERATOR 7	0	2259	2259	
GENERATOR 8	0	1259	38	
GENERATOR 9	0	107	0	
GENERATOR 10	0	0	0	
CHILLER OPERATING HOURS				
CHILLER 1	2587	2576	2575	
CHILLER 2	1023	1002	1002	
CHILLER 3	295	252	252	
CHILLER 4	0	0	0	
BOILER OPERATING HOURS				
BOILER 1	0	1562	1545	
BOILER 2	0	646	636	
RECOVERABLE HEAT USED, MBTU	0.	22222170.	22611029.	
RECOVERABLE HEAT UNUSED, MBTU	0.	26795935.	27865392.	

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60 FOOT BUILDING - TOTAL ENERGY SYSTEMS 1, 2, 3, AND 4 - 50 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #4 ABSORPTION-50 ACRES SYSTEM 1

SYSTEM A1 DDA 3000KW GT
SYSTEM A2 SOLAR 800KW GT
SYSTEM A3 SOLAR 1200KW GT/ST
SYSTEM A4 SOLAR 2500KW GT

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	SYSTEM A3 ** TOTAL **	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	19203471.	19193159.	20212964.	19267870.
PEAK KW DEMAND (60 MIN BASIS)	7659.	6200.	6736.	6890.
AUXILIARY FUEL CONSUMPTION	2768589. GAL	2851760. GAL	1965699. GAL	3187369. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	8760
GENERATOR 2	5042	5042	5042	5042
GENERATOR 3	0	5042	5042	840
GENERATOR 4	0	5042	2645	0
GENERATOR 5	0	2731	1139	0
GENERATOR 6	0	2259	248	0
GENERATOR 7	0	1165	0	0
GENERATOR 8	0	0	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2424	2424	2439	2424
CHILLER 2	929	929	981	929
CHILLER 3	194	194	278	194
CHILLER 4	0	0	0	0
RECOVERABLE HEAT USED, MBTU	41617192.	41652389.	0.	41397400.
RECOVERABLE HEAT UNUSED, MBTU	171836689.	149871642.	0.	153461223.

60 FOOT BUILDING - TOTAL ENERGY SYSTEMS 5, 6, AND 7 - 50 ACRES
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E4 DIESEL 50 ACRES

SYSTEM A5 SOLAR 3750Kw GTOST
SYSTEM A6 CUMMINS 690KW DIES
SYSTEM A7 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A5	SYSTEM A6	SYSTEM A7	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	20212964.	19147060.	19146745.	
PEAK KW DEMAND (60 MIN BASIS)	6736.	5302.	5302.	
AUXILIARY FUEL CONSUMPTION	2148314. GAL	1879564. GAL	1817422. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	
ENGINE OPERATING HOURS				
GENERATOR 1	8760	8760	8760	
GENERATOR 2	3495	5042	5042	
GENERATOR 3	0	5042	5042	
GENERATOR 4	0	5042	5042	
GENERATOR 5	0	5042	2646	
GENERATOR 6	0	2278	2259	
GENERATOR 7	0	2259	775	
GENERATOR 8	0	620	0	
GENERATOR 9	0	0	0	
GENERATOR 10	0	0	0	
CHILLER OPERATING HOURS				
CHILLER 1	2439	2424	2424	
CHILLER 2	981	929	929	
CHILLER 3	278	194	194	
CHILLER 4	0	0	0	
BOILER OPERATING HOURS				
BOILER 1	0	1578	1566	
BOILER 2	0	611	602	
RECOVERABLE HEAT USED, MBTU	0.	20224515.	20521828.	
RECOVERABLE HEAT UNUSED, MBTU	0.	26642021.	27502370.	

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Changed Facility Operating Hours Data

This section of the appendix contains the conputer output for both commercial power systems and total energy systems investigated for cost differentials associated with changes in facility operating hours as discussed in the "Energy Systems Selection" section of this report. For each of the building heights, the best commercial power system, the Detroit Diesel Allison gas turbine system, the Solar Saturn gas turbine/steam turbine system, and the Detroit Diesel Allison diesel system were analyzed. Pages E-12-37 through E-12-40 include the output for the normal eight hour per day plus a partial night shift operation. Pages E-12-41 through E-12-45 give the comparable data for 16 hour per day operation and pages E-12-46 through E-12-49 cover 24 hour per day operation.

30 FOOT BUILDING - NORFOLK - 8 HR
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #1

** TOTAL **

SYSTEM E1 TWO-950 TON, TWO-525 TON, OPENS
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	24869910.	24869910.	23699665.	23729245.
PEAK KW DEMAND (60 MIN BASIS)	8485.	8485.	7164.	7164.
AUXILIARY FUEL CONSUMPTION	0. GAL	2379202. GAL	3272714. GAL	2124409. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	1626	5042
GENERATOR 4	0	3700	0	5042
GENERATOR 5	0	2266	0	5142
GENERATOR 6	0	1252	0	2435
GENERATOR 7	0	325	0	2259
GENERATOR 8	0	0	0	1335
GENERATOR 9	0	0	0	370
GENERATOR 10	0	0	0	1
CHILLER OPERATING HOURS				
CHILLER 1	3075	3075	2942	2942
CHILLER 2	1533	1533	581	581
CHILLER 3	332	332	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1707
BOILER 2	0	0	0	265
RECOVERABLE HEAT USED, MBTU	0.	0.	45519984.	30222316.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	20565128.	28688582.

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40 FOOT BUILDING - NORFOLK - 8 HR

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #2

SYSTEM E1 ONE-400 TON THREE-725 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 745KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	22784995.	22784995.	21720314.	21743999.	
PEAK KW DEMAND (60 MIN BASIS)	7502.	7502.	6375.	6375.	
AUXILIARY FUEL CONSUMPTION	0. GAL	2197976. GAL	3000227. GAL	1932220. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.	
ENGINE OPERATING HOURS					
GENERATOR 1	0	8760	8760	8760	
GENERATOR 2	0	5042	5042	5042	
GENERATOR 3	0	5042	348	5042	
GENERATOR 4	0	3266	0	5042	
GENERATOR 5	0	2260	0	3879	
GENERATOR 6	0	638	0	2259	
GENERATOR 7	0	4	0	2259	
GENERATOR 8	0	0	0	559	
GENERATOR 9	0	0	0	1	
GENERATOR 10	0	0	0	0	
CHILLER OPERATING HOURS					
CHILLER 1	2877	2877	2705	2705	
CHILLER 2	1494	1494	660	660	
CHILLER 3	424	424	0	0	
CHILLER 4	0	0	0	0	
BOILER OPERATING HOURS					
BOILER 1	0	0	0	1441	
BOILER 2	0	0	0	138	
RECOVERABLE HEAT USED, MBTU	0.	0.	37415912.	24825573.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	192874399.	29181326.	

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A GENERAL WAREHOUSE MODULE CONCEPTUAL DESIGN AND COST ANALYSIS.--ETC(U)
SEP 76 R T ALEXANDER, T J CARMICHAEL

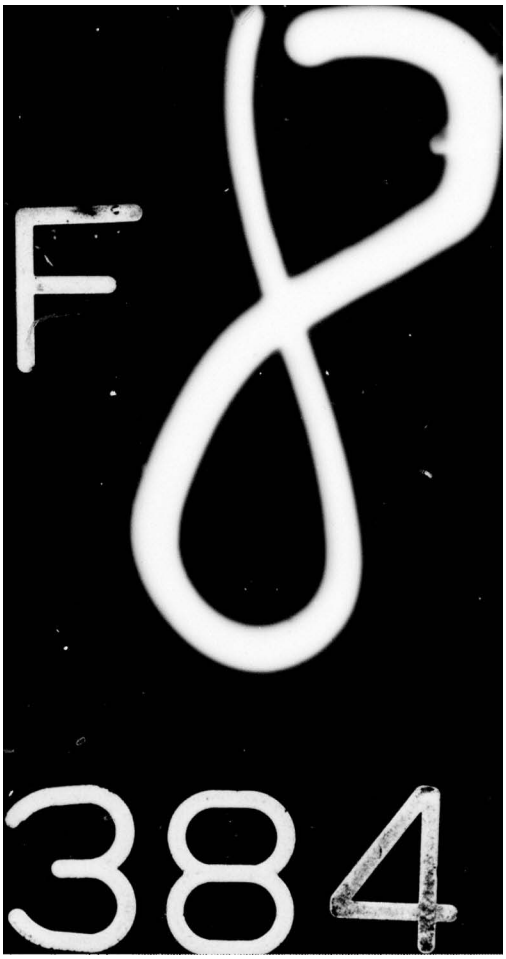
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50 FOOT BUILDING - NORFOLK - 8 HR

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #3

SYSTEM F1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM F1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	21793621.	21793621.	20949891.	21011176.
PEAK KW DEMAND (60 MIN BASIS)	6960.	6960.	5917.	5917.
AUXILIARY FUEL CONSUMPTION	0. GAL	2104786. GAL	2912032. GAL	1856858. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	4	5042
GENERATOR 4	0	3086	0	5042
GENERATOR 5	0	1785	0	3774
GENERATOR 6	0	321	0	2259
GENERATOR 7	0	0	0	2259
GENERATOR 8	0	0	0	94
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2732	2732	2572	2572
CHILLER 2	1304	1304	640	640
CHILLER 3	352	352	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1320
BOILER 2	0	0	0	99
RECOVERABLE HEAT USED, MBTU	0.	0.	33839130.	22475233.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	189814126.	29650128.

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60 FOOT BUILDING - NORFOLK - 8 HR

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING 54

** TOTAL **

SYSTEM A1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 745KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM A1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	20858734.	20858734.	20139419.	20159054.
PEAK KW DEMAND (60 MIN BASIS)	6428.	6428.	5508.	5508.
AUXILIARY FUEL CONSUMPTION	0. GAL	2015957. GAL	2847588. GAL	1777930. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	0	5042
GENERATOR 4	0	2775	0	5042
GENERATOR 5	0	1219	0	3502
GENERATOR 6	0	234	0	2259
GENERATOR 7	0	0	0	1145
GENERATOR 8	0	0	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2567	2567	2420	2420
CHILLER 2	1212	1212	582	582
CHILLER 3	269	269	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1246
BOILER 2	0	0	0	63
RECOVERABLE HEAT USED, MBTU	0.	0.	30890569.	20505504.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	18829381.	29551310.

30 FOOT BUILDING - NORFOLK - 16 HR
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #1

** TOTAL **

SYSTEM E1 TWO-950 TON, TWO-525 TON, OPENS
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	31969929.	31969929.	30374439.	30408749.
PEAK KW DEMAND (60 MIN BASIS)	7838.	7838.	6572.	6602.
AUXILIARY FUEL CONSUMPTION	0. GAL	3026064. GAL	3969732. GAL	2693077. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	3621	5042
GENERATOR 4	0	5042	0	5042
GENERATOR 5	0	5042	0	5042
GENERATOR 6	0	2876	0	5042
GENERATOR 7	0	629	0	5042
GENERATOR 8	0	0	0	4163
GENERATOR 9	0	0	0	740
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	3346	3346	3250	3250
CHILLER 2	2093	2093	930	930
CHILLER 3	629	629	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1901
BOILER 2	0	0	0	389
RECOVERABLE HEAT USED, MBTU	0.	0.	59453176.	40874112.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	242968578.	34075422.

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40 FOOT BUILDING - NORFOLK - 16 HR
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #2

SYSTEM F1 ONE-400 TON THREE-725 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM F1	SYSTEM A2	SYSTEM A3	SYSTEM A4	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	28740088.	28740088.	27334196.	27361016.	
PEAK KW DEMAND (60 MIN BASIS)	7090.	7090.	5934.	5904.	
AUXILIARY FUEL CONSUMPTION	0. GAL	2746160. GAL	3459039. GAL	2407830. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.	
ENGINE OPERATING HOURS					
GENERATOR 1	0	8760	8760	8760	
GENERATOR 2	0	5042	5042	5042	
GENERATOR 3	0	5042	705	5042	
GENERATOR 4	0	5042	0	5042	
GENERATOR 5	0	5042	0	5042	
GENERATOR 6	0	1414	0	5042	
GENERATOR 7	0	0	0	5042	
GENERATOR 8	0	0	0	1204	
GENERATOR 9	0	0	0	0	
GENERATOR 10	0	0	0	0	
CHILLER OPERATING HOURS					
CHILLER 1	2997	2997	2882	2882	
CHILLER 2	2006	2006	954	954	
CHILLER 3	725	725	0	0	
CHILLER 4	0	0	0	0	
BOILER OPERATING HOURS					
BOILER 1	0	0	0	1586	
BOILER 2	0	0	0	202	
RECOVERABLE HEAT USED, MBTU	0.	0.	47345888.	32392303.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	215245791.	35162045.	

50 FOOT BUILDING - NORFOLK - 16 HR

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #3

** TOTAL **

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	27285023.	27285023.	26198001.	26222061.
PEAK KW DEMAND (60 MIN BASIS)	6733.	6733.	5605.	5635.
AUXILIARY FUEL CONSUMPTION	0. GAL	2605367. GAL	3305394. GAL	2296553. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	0	5042
GENERATOR 4	0	5042	0	5042
GENERATOR 5	0	4214	0	5042
GENERATOR 6	0	625	0	5042
GENERATOR 7	0	0	0	5042
GENERATOR 8	0	0	0	171
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2907	2907	2796	2796
CHILLER 2	1767	1767	900	900
CHILLER 3	625	625	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1456
BOILER 2	0	0	0	148
RECOVERABLE HEAT USED, MBTU	0.	0.	42626544.	29186165.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	208388409.	35486777.

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60 FOOT BUILDING - NORFOLK - 16 HR
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #4

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM 44 ** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	26037381.	26037381.	25070311.	25092736.
PEAK KW DEMAND (60 MIN BASIS)	6428.	6428.	5342.	5372.
AUXILIARY FUEL CONSUMPTION	0. GAL	2480170. GAL	3220570. GAL	2191217. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	0	5042
GENERATOR 4	0	5042	0	5042
GENERATOR 5	0	2796	0	5042
GENERATOR 6	0	451	0	5042
GENERATOR 7	0	0	0	2096
GENERATOR 8	0	0	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2692	2692	2573	2573
CHILLER 2	1712	1712	818	818
CHILLER 3	469	469	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1347
BOILER 2	0	0	0	98
RECOVERABLE HEAT USED, MBTU	0.	0.	39529297.	26431311.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	206620428.	35484598.

30 FOOT BUILDING - NORFOLK - 24 HR
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E1

SYSTEM E1 TWO-950 TON, TWO-525 TON, OPENS
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	55211126.	55211126.	52521734.	52576769.
PEAK KW DEMAND (60 MIN BASIS)	7838.	7838.	6578.	6638.
AUXILIARY FUEL CONSUMPTION	0. GAL	5107453. GAL	6351197. GAL	4548849. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	8760	8760	8760
GENERATOR 3	0	8760	7302	8760
GENERATOR 4	0	8760	0	8760
GENERATOR 5	0	8760	0	8760
GENERATOR 6	0	6053	0	8760
GENERATOR 7	0	716	0	8760
GENERATOR 8	0	0	0	8760
GENERATOR 9	0	0	0	403.
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	6473	6473	6271	6271
CHILLER 2	3356	3356	1111	1111
CHILLER 3	716	716	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	3239
BOILER 2	0	0	0	430
RECOVERABLE HEAT USED, MBTU	0.	0.	102714749.	76017780.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	376885532.	51843501.

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40 FOOT BUILDING - NORFOLK - 24 HR
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #2

SYSTEM E1 ONE-400 TON THREE-725 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	49075559.	49075559.	46808835.	46851570.
PEAK KW DEMAND (60 MIN BASIS)	7090.	7090.	5940.	5970.
AUXILIARY FUEL CONSUMPTION	0. GAL	4563306. GAL	5298564. GAL	4014280. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	8760	8760	8760
GENERATOR 3	0	8760	861	8760
GENERATOR 4	0	8760	0	8760
GENERATOR 5	0	8760	0	8760
GENERATOR 6	0	2226	0	8760
GENERATOR 7	0	0	0	8760
GENERATOR 8	0	0	0	1322
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	5603	5603	5429	5429
CHILLER 2	3348	3348	1182	1182
CHILLER 3	853	853	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	2020
BOILER 2	0	0	0	229
RECOVERABLE HEAT USED, MBTU	0.	0.	77846620.	57521167.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	31852803.	56351513.

50 FOOT BUILDING - NORFOLK - 24 HR
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING 33

** TOTAL **

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	46439760.	46439760.	44748059.	44785289.
PEAK KW DEMAND (60 MIN BASIS)	6733.	6733.	5610.	5640.
AUXILIARY FUEL CONSUMPTION	0. GAL	4339180. GAL	5060286. GAL	3822423. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	8760	8760	8760
GENERATOR 3	0	8760	0	8760
GENERATOR 4	0	8760	0	8760
GENERATOR 5	0	8758	0	8760
GENERATOR 6	0	719	0	8760
GENERATOR 7	0	0	0	8760
GENERATOR 8	0	0	0	204
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	5579	5579	5351	5351
CHILLER 2	2842	2842	1057	1057
CHILLER 3	719	719	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	2318
BOILER 2	0	0	0	164
RECOVERABLE HEAT USED, MBTU	0.	0.	68878896.	51237796.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	309965840.	57692723.

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60 FOOT BUILDING - NORFOLK - 24 HR
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING =4

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	44244879.	44244879.	42692740.	42726505.
PEAK KW DEMAND (60 MIN BASIS)	6428.	6423.	5345.	5375.
AUXILIARY FUEL CONSUMPTION	0. GAL	411232B. GAL	4905696. GAL	3633085. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	8760	8760	8760
GENERATOR 3	0	8760	0	8760
GENERATOR 4	0	8760	0	8760
GENERATOR 5	0	5841	0	8760
GENERATOR 6	0	532	0	8760
GENERATOR 7	0	0	0	5841
GENERATOR 8	0	0	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	4864	4864	4597	4597
CHILLER 2	2950	2950	972	972
CHILLER 3	532	532	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	2141
BOILER 2	0	0	0	110
RECOVERABLE HEAT USED, MBTU	0.	0.	60441253.	45116737.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	307926764.	58851411.

Changed Geographic Region Data

This section of the appendix contains the output data for the study covering changes in climate included in the "Internal Energy Systems Cost Summary" section of this report. The equipment systems studied were the same as those detailed in the preceding section of this appendix. Pages E-12-50 through E-12-53 contain the data for Harrisburg, Pennsylvania. Pages E-12-54 through E-12-57, E-12-58 through E-12-61, and E-12-62 through E-12-65 cover Oklahoma City, Oklahoma; Los Angeles, California; and Oakland, California, respectively.

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30 FOOT BUILDING - HARRISBURG

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E1

** TOTAL **

SYSTEM E1 TWO-950 TON, TWO-525 TON, OPENS
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	24412514.	24412514.	23436450.	23459820.
PEAK KW DEMAND (60 MIN BASIS)	7881.	7881.	6894.	6894.
AUXILIARY FUEL CONSUMPTION	0. GAL	2336372. GAL	3235327. GAL	2064567. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	1447	5042
GENERATOR 4	0	3532	0	5042
GENERATOR 5	0	2267	0	5042
GENERATOR 6	0	1066	0	2373
GENERATOR 7	0	235	0	2259
GENERATOR 8	0	0	0	1757
GENERATOR 9	0	0	0	272
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2807	2807	2636	2636
CHILLER 2	1276	1276	412	412
CHILLER 3	243	243	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1356
BOILER 2	0	0	0	172
RECOVERABLE HEAT USED, MBTU	0.	0.	17570101.	26182224.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	210716818.	32111280.

40 FOOT BUILDING - HARRISBURG

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #2

** TOTAL **

SYSTEM E1 ONE-400 TON THREE-725 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	22308959.	22308959.	21460288.	21478453.
PEAK KW DEMAND (60 MIN BASIS)	7121.	7121.	6093.	6093.
AUXILIARY FUEL CONSUMPTION	0. GAL	2155333. GAL	2971772. GAL	1877949. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	259	5042
GENERATOR 4	0	3049	0	5042
GENERATOR 5	0	2259	0	3706
GENERATOR 6	0	488	0	2259
GENERATOR 7	0	0	0	2259
GENERATOR 8	0	0	0	412
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2556	2556	2393	2393
CHILLER 2	1212	1212	463	463
CHILLER 3	299	299	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1114
BOILER 2	0	0	0	97
RECOVERABLE HEAT USED, MBTU	0.	0.	30226537.	21048806.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	197913330.	32358723.

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50 FOOT BUILDING - HARRISBURG

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #3

** TOTAL **

SYSTEM #1 TWO-400 TON, TWO-950 TON
SYSTEM #2 SOLAR 1200KW GT/ST
SYSTEM #3 ODA 3000KW GT
SYSTEM #4 ODA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM #1	SYSTEM #2	SYSTEM #3	SYSTEM #4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	21365442.	21365442.	20726061.	20742351.
PEAK KW DEMAND (60 MIN BASIS)	6746.	6746.	5641.	5650.
AUXILIARY FUEL CONSUMPTION	0. GAL	2065202. GAL	2891525. GAL	1805713. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	0	5042
GENERATOR 4	0	2489	0	5042
GENERATOR 5	0	1591	0	3588
GENERATOR 6	0	221	0	2259
GENERATOR 7	0	0	0	2259
GENERATOR 8	0	0	0	58
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2400	2400	2234	2234
CHILLER 2	1075	1075	456	456
CHILLER 3	235	235	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1012
BOILER 2	0	0	0	76
RECOVERABLE HEAT USED, MBTU	0.	0.	27056129.	18821749.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	195144787.	32709702.

60 FOOT BUILDING - HARRISBURG

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING =4

SYSTEM F1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 CDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM F1	SYSTEM A2	SYSTEM A3	SYSTEM A4 ** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	20428658.	20428658.	19856626.	19871671.
PEAK KW DEMAND (60 MIN BASIS)	6425.	6425.	5354.	5384.
AUXILIARY FUEL CONSUMPTION	0. GAL	1976823. GAL	2826015. GAL	1728103. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	0	5042
GENERATOR 4	0	2634	0	5042
GENERATOR 5	0	1065	0	3322
GENERATOR 6	0	165	0	2259
GENERATOR 7	0	0	0	998
GENERATOR 8	0	0	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2224	2224	2056	2056
CHILLER 2	971	971	417	417
CHILLER 3	180	180	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	950
BOILER 2	0	0	0	53
RECOVERABLE HEAT USED, MBTU	0.	0.	24468635.	16979305.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	19316169.	12451056.

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30 FOOT BUILDING - OKLAHOMA CITY
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING =1

** TOTAL **

SYSTEM E1 TWO-950 TON, TWO-525 TON, OPENS
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	25370234.	25370234.	23926692.	23964432.
PEAK KW DEMAND (60 MIN BASIS)	9074.	9074.	7388.	7388.
AUXILIARY FUEL CONSUMPTION	0. GAL	2225204. GAL	3299609. GAL	2203088. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	1726	5042
GENERATOR 4	0	3904	0	5042
GENERATOR 5	0	2358	0	5042
GENERATOR 6	0	1399	0	2554
GENERATOR 7	0	431	0	2259
GENERATOR 8	0	0	0	1876
GENERATOR 9	0	0	0	472
GENERATOR 10	0	0	0	3
CHILLER OPERATING HOURS				
CHILLER 1	3339	3339	3188	3188
CHILLER 2	1823	1823	825	825
CHILLER 3	527	527	2	2
CHILLER 4	2	2	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1469
BOILER 2	0	0	0	527
RECOVERABLE HEAT USED, MBTU	0.	0.	54744460.	33396161.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	199438986.	26066499.

40 FOOT BUILDING - OKLAHOMA CITY
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #2

SYSTEM E1 ONE-400 TON THREE-725 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	23248277.	23248277.	21922677.	21954672.
PEAK KW DEMAND (60 MIN BASIS)	8295.	8295.	6742.	6742.
AUXILIARY FUEL CONSUMPTION	0. GAL	2236668. GAL	3026907. GAL	2005565. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	465	5042
GENERATOR 4	0	3345	0	5042
GENERATOR 5	0	2315	0	4020
GENERATOR 6	0	717	0	2271
GENERATOR 7	0	24	0	2259
GENERATOR 8	0	0	0	528
GENERATOR 9	0	0	0	4
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	3073	3073	2896	2896
CHILLER 2	1785	1785	914	914
CHILLER 3	654	654	22	22
CHILLER 4	22	22	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1712
BOILER 2	0	0	0	421
RECOVERABLE HEAT USED, MBTU	0.	0.	45686450.	27350523.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	196647858.	27131498.

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50 FOOT BUILDING - OKLAHOMA CITY
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E3

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	22223291.	22223291.	21180677.	21210167.	
PEAK KW DEMAND (60 MIN BASIS)	7752.	7752.	6286.	6286.	
AUXILIARY FUEL CONSUMPTION	0. GAL	2142215. GAL	2928645. GAL	1928544. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.	
ENGINE OPERATING HOURS					
GENERATOR 1	0	8760	8760	8760	
GENERATOR 2	0	5042	5042	5042	
GENERATOR 3	0	5042	26	5042	
GENERATOR 4	0	3217	0	5042	
GENERATOR 5	0	1828	0	3909	
GENERATOR 6	0	433	0	2260	
GENERATOR 7	0	1	0	2059	
GENERATOR 8	0	0	0	203	
GENERATOR 9	0	0	0	0	
GENERATOR 10	0	0	0	0	
CHILLER OPERATING HOURS					
CHILLER 1	2943	2943	2773	2773	
CHILLER 2	1589	1589	904	904	
CHILLER 3	587	587	23	23	
CHILLER 4	1	1	0	0	
BOILER OPERATING HOURS					
BOILER 1	0	0	0	1594	
BOILER 2	0	0	0	372	
RECOVERABLE HEAT USED, MBTU	0.	0.	42055559.	25064193.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	182802890.	27521125.	

60 FOOT BUILDING - OKLAHOMA CITY
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E4

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	21269976.	21269976.	20310901.	20339666.
PEAK KW DEMAND (60 MIN BASIS)	6800.	6800.	5827.	5827.
AUXILIARY FUEL CONSUMPTION	0. GAL	2054095. GAL	2860758. GAL	1847154. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	2	5042
GENERATOR 4	0	2902	0	5042
GENERATOR 5	0	1337	0	3576
GENERATOR 6	0	370	0	2259
GENERATOR 7	0	0	0	1255
GENERATOR 8	0	0	0	3
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2792	2792	2618	2618
CHILLER 2	1493	1493	841	841
CHILLER 3	511	511	11	11
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1525
BOILER 2	0	0	0	326
RECOVERABLE HEAT USED, MBTU	0.	0.	39035750.	23096765.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	191071265.	27371311.

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30 FOOT BUILDING - LOS ANGELES

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #1

** TOTAL **

SYSTEM E1 TWO-950 TON, TWO-525 TON, OPENS
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	25316851.	25316851.	24180020.	24203945.
PEAK KW DEMAND (60 MIN BASIS)	7861.	7861.	6593.	6623.
AUXILIARY FUEL CONSUMPTION	0. GAL	2427926. GAL	3341067. GAL	2086085. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	1951	5042
GENERATOR 4	0	4256	0	5042
GENERATOR 5	0	2259	0	5042
GENERATOR 6	0	1705	0	2361
GENERATOR 7	0	71	0	2259
GENERATOR 8	0	0	0	2058
GENERATOR 9	0	0	0	207
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	4134	4134	3815	3815
CHILLER 2	1592	1592	230	230
CHILLER 3	72	72	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1563
BOILER 2	0	0	0	32
RECOVERABLE HEAT USED, MBTU	0.	0.	44528967.	36956733.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	211960799.	22965076.

40 FOOT BUILDING - LOS ANGELES

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING =2

** TOTAL **

SYSTEM E1 ONE-400 TON THREE-725 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	23091942.	23091942.	22199930.	22215390.
PEAK KW DEMAND (60 MIN BASIS)	7101.	7101.	5955.	5965.
AUXILIARY FUEL CONSUMPTION	0. GAL	2215026. GAL	3020031. GAL	1889764. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	172	5042
GENERATOR 4	0	3047	0	5042
GENERATOR 5	0	2259	0	4660
GENERATOR 6	0	622	0	2259
GENERATOR 7	0	0	0	2259
GENERATOR 8	0	0	0	614
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	4029	4029	3600	3600
CHILLER 2	1374	1374	210	210
CHILLER 3	89	89	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	1915
BOILER 2	0	18	0	15
RECOVERABLE HEAT USED, MBTU	0.	0.	33665853.	29016675.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	197774442.	25991281.

E-12-59

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50 FOOT BUILDING - LOS ANGELES

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E3

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 745KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	22245394.	22245394.	21531765.	21545130.	
PEAK KW DEMAND (60 MIN BASIS)	6727.	6727.	5621.	5651.	
AUXILIARY FUEL CONSUMPTION	0. GAL	2131693. GAL	2953125. GAL	1822802. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.	
ENGINE OPERATING HOURS					
GENERATOR 1	0	8760	8760	8760	
GENERATOR 2	0	5042	5042	5042	
GENERATOR 3	0	5042	0	5042	
GENERATOR 4	0	2794	0	5042	
GENERATOR 5	0	2059	0	4617	
GENERATOR 6	0	69	0	2259	
GENERATOR 7	0	0	0	2259	
GENERATOR 8	0	0	0	18	
GENERATOR 9	0	0	0	0	
GENERATOR 10	0	0	0	0	
CHILLER OPERATING HOURS					
CHILLER 1	3844	3844	3381	3381	
CHILLER 2	1306	1306	176	176	
CHILLER 3	70	70	0	0	
CHILLER 4	0	0	0	0	
BOILER OPERATING HOURS					
BOILER 1	0	0	0	878	
BOILER 2	0	0	0	13	
RECOVERABLE HEAT USED, MBTU	0.	0.	29745053.	25896070.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	196801531.	27364779.	

60 FOOT BUILDING - LOS ANGELES

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #4

SYSTEM F1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM F1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	21289938.	21289938.	20647870.	20659660.
PEAK KW DEMAND (60 MIN BASIS)	6409.	5409.	5353.	5383.
AUXILIARY FUEL CONSUMPTION	0. GAL	2048686. GAL	2886310. GAL	1744927. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	0	5042
GENERATOR 4	0	2519	0	5042
GENERATOR 5	0	1731	0	4260
GENERATOR 6	0	44	0	2259
GENERATOR 7	0	0	0	1594
GENERATOR 8	0	0	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	3566	3566	3104	3104
CHILLER 2	1145	1145	140	140
CHILLER 3	44	44	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	774
BOILER 2	0	0	0	12
RECOVERABLE HEAT USED, MBTU	0.	0.	26419105.	23194959.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	195528244.	27935285.

E-121-61

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30 FOOT BUILDING - OAKLAND

EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING E1

SYSTEM E1 TWO-950 TON, TWO-525 TON, OPENS
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4	** TOTAL **
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.	
ELECTRICAL CONSUMPTION, KWH	24364511.	24364511.	23655950.	23667410.	
PEAK KW DEMAND (60 MIN BASIS)	7649.	7649.	6516.	6546.	
AUXILIARY FUEL CONSUMPTION	0. GAL	2335087. GAL	3282031. GAL	2000911. GAL	
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.	
ENGINE OPERATING HOURS					
GENERATOR 1	0	8760	8760	8760	
GENERATOR 2	0	5042	5042	5042	
GENERATOR 3	0	5042	1755	5042	
GENERATOR 4	0	3560	0	5042	
GENERATOR 5	0	2259	0	5042	
GENERATOR 6	0	1348	0	2303	
GENERATOR 7	0	34	0	2259	
GENERATOR 8	0	0	0	1690	
GENERATOR 9	0	0	0	72	
GENERATOR 10	0	0	0	0	
CHILLER OPERATING HOURS					
CHILLER 1	3062	3062	2728	2728	
CHILLER 2	851	851	79	79	
CHILLER 3	34	34	0	0	
CHILLER 4	0	0	0	0	
BOILER OPERATING HOURS					
BOILER 1	0	0	0	749	
BOILER 2	0	0	0	15	
RECOVERABLE HEAT USED, MBTU	0.	0.	27889327.	24363806.	
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	224177617.	34353501.	

40 FOOT BUILDING - OAKLAND
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #2

** TOTAL **

SYSTEM F1 ONE-400 TON THREE-725 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM F1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	22060737.	22060737.	21596755.	21603565.
PEAK KW DEMAND (60 MIN BASIS)	6984.	6984.	5873.	5902.
AUXILIARY FUEL CONSUMPTION	0. GAL	2125455. GAL	2962919. GAL	1811551. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	58	5042
GENERATOR 4	0	2611	0	5042
GENERATOR 5	0	2259	0	4206
GENERATOR 6	0	341	0	2259
GENERATOR 7	0	0	0	2259
GENERATOR 8	0	0	0	371
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2601	2601	2196	2196
CHILLER 2	662	662	71	71
CHILLER 3	44	44	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	451
BOILER 2	0	0	0	3
RECOVERABLE HEAT USED, MBTU	0.	0.	18162099.	16365049.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	2090399665.	3726560?.

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50 FOOT BUILDING - OAKLAND
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING =3

** TOTAL **

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
TOTAL GAS CONSUMP.. 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP.. 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION. KWH	21291375.	21291375.	20898180.	20904210.
PEAK KW DEMAND (60 MIN BASIS)	6511.	6511.	5552.	5582.
AUXILIARY FUEL CONSUMPTION	0. GAL	2050336. GAL	2904724. GAL	1748754. GAL
DIR. PROC. GAS CONSUMP.. 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	0	5042
GENERATOR 4	0	2468	0	5042
GENERATOR 5	0	1864	0	4177
GENERATOR 6	0	33	0	2259
GENERATOR 7	0	0	0	2259
GENERATOR 8	0	0	0	3
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2444	2444	2055	2055
CHILLER 2	655	655	60	60
CHILLER 3	33	33	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	490
BOILER 2	0	0	0	2
RECOVERABLE HEAT USED. MBTU	0.	0.	16089086.	14609504.
RECOVERABLE HEAT UNUSED. MBTU	0.	0.	207044388.	37249304.

60 FOOT BUILDING - OAKLAND
EQUIPMENT SELECTION AND ENERGY CONSUMPTION

BUILDING #4

SYSTEM E1 TWO-400 TON, TWO-950 TON
SYSTEM A2 SOLAR 1200KW GT/ST
SYSTEM A3 DDA 3000KW GT
SYSTEM A4 DDA 795KW DIES

FUEL AND POWER CONSUMPTION	SYSTEM E1	SYSTEM A2	SYSTEM A3	SYSTEM A4
			** TOTAL **	
TOTAL GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
PEAK DAY GAS CONSUMP., 1000 CU FT	0.	0.	0.	0.
ELECTRICAL CONSUMPTION, KWH	20265547.	20265547.	19913267.	19918277.
PEAK KW DEMAND (60 MIN BASIS)	6208.	6208.	5299.	5314.
AUXILIARY FUEL CONSUMPTION	0. GAL	1957193. GAL	2830221. GAL	1667398. GAL
DIR. PROC. GAS CONSUMP., 1000 CF	0.	0.	0.	0.
ENGINE OPERATING HOURS				
GENERATOR 1	0	8760	8760	8760
GENERATOR 2	0	5042	5042	5042
GENERATOR 3	0	5042	0	5042
GENERATOR 4	0	2336	0	5042
GENERATOR 5	0	1153	0	3754
GENERATOR 6	0	17	0	2259
GENERATOR 7	0	0	0	1036
GENERATOR 8	0	0	0	0
GENERATOR 9	0	0	0	0
GENERATOR 10	0	0	0	0
CHILLER OPERATING HOURS				
CHILLER 1	2222	2222	1874	1874
CHILLER 2	611	611	52	52
CHILLER 3	17	17	0	0
CHILLER 4	0	0	0	0
BOILER OPERATING HOURS				
BOILER 1	0	0	0	334
BOILER 2	0	0	0	0
RECOVERABLE HEAT USED, MBTU	0.	0.	14346943.	13126697.
RECOVERABLE HEAT UNUSED, MBTU	0.	0.	203590994.	363865 10.

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APPENDIX E-13

ANNUAL COST ESTIMATE FOR EMCS

The purpose of this appendix is to establish the estimated cost of an EMCS based on the number of control and monitor points. The parameters are listed, a sample calculation is shown, and the results are listed.

In order to establish an annual cost of an EMCS it is necessary to amortize the initial cost over a 25 year period at 10 percent interest. It is also necessary to determine a maintenance cost. The manufacturers recommend that average yearly maintenance costs are five percent of the initial system cost for the entire system (Bosch, 1975:5-5).

The average life of the hardware and software options is eight years. Therefore, they will be replaced at the beginning of the eighth and sixteenth year point. It is assumed these systems have no salvage value. It is also assumed that the control and monitoring points and their associated wiring have a 25 year life (Bosch, 1975:5-1).

The calculation of the annual cost for a 500 point control and monitoring system is as follows:

Initial hardware cost = $72,450.00

Initial software cost = $51,000.00

Initial cost for control and monitor points = $190,000.00

Total initial cost = $190,000 + $72,450 + $51,000 = $313,450.00

Maintenance cost = 0.05(313,450) = $15,673.00

(P/F,10%,8) = 123,450(.4665) = $57,589.00

(P/F,10%,16) = 123,450(.2176) = $26,863.00

313,450 + 57,589 + 26,863 = $397,902.00

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The initial annual cost is:

(A/P,10%,25) = 397,902(.11017) = $43,837.00

Annual cost = $15,673.00 + $43,837.00 = $59,510.00

The costs for the 1000, 1500, 2000, 3000, and 5000 point control and monitoring system are shown in Table E-13-1. The method presented above was used to calculate the annual costs.

TABLE E-13-1

ANNUAL COSTS OF EMCS BASED ON THE NUMBER OF CONTROL AND MONITORING POINTS

NO. OF POINTS IN SYSTEM	INITIAL ANNUAL COST	MAINTENANCE COST	TOTAL ANNUAL COST
500	$ 43,837.00	$15,673.00	$ 59,510.00
1000	$ 61,464.00	$23,673.00	$ 85,137.00
1500	$ 79,091.00	$31,673.00	$110,764.00
2000	$ 97,820.00	$40,173.00	$137,993.00
3000	$135,278.00	$57,173.00	$192,451.00
5000	$210,194.00	$91,173.00	$301,367.00

Freezer/Cooler Appendix Symbols

CFM - Cubic feet per minute of air

c_p - Specific heat in BTU per hour per pound mass (BTU/hr-lbm)

p - Absolute pressure in pound force per sq in (lbf/sq in)

Q - Heat gain or loss in BTU/hr

R - Gas constant in foot-pound force per pound mass-^{o}Rankine (ft-lbf/lbm-^{o}R)

ρ - Density in lbm/cu ft

T - Absolute temperature in ^{o}Rankine

Δt - Temperature difference in ^{o}F

t_{rm} - Design temperature of room in ^{o}F

t_{sa} - Temperature of supply air

U - Coefficient of heat transfer in BTU/hr-sq ft

v - Specific volume in cu ft/lbm

vol - Volume in cubic feet

APPENDIX E-14

FREEZER/COOLER

This appendix presents the calculations and data for the freezer and cooler areas. The subjects discussed are the derivation of fan horsepower for the air handler units, the determination of the cooling of product load, economic data on refrigeration systems analyzed, the trade off of insulation costs versus operating costs, and determination of total costs of the freezer, cooler, and loading dock.

Derivation of Fan Horsepower. To calculate the fan horsepower, the supply air volume had to be established, and from that, a fan horsepower was determined using fan performance curves.

The supply air volume is the cubic feet per minute of air required across the cooling coil to provide the required amount of refrigeration. This is normally found by the normal air conditioning equation (Carrier, 1972:119).

$$Q = 1.08(CFM)(t_{rm} - t_{sa}) \qquad \text{(E-14-1)}$$

However, this equation is based on standard air which is at 70°F and 50 percent relative humidity. At -10°F and 32°F the 1.08 factor in the standard air conditioning formula is not accurate, thus a factor must be calculated. This was accomplished for both the freezer and cooler. The calculation is done here for the freezer.

The 1.08 value, or factor, is defined by the specific heat divided by the specific volume and multiplied by 60 minutes per hour. This is shown in Equation (E-14-2).

$$\text{Factor} = c_p/v(60 \text{ min/hr}) \qquad \text{(E-14-2)}$$

The specific volume for a given pressure and temperature is found by the Ideal Gas Law, which is Equation (E-14-3).

$$v = RT/p \qquad \text{(E-14-3)}$$

Substituting Equations (E-14-2) and (E-14-3) into Equation (E-14-1) and solving for the CFM, the equation becomes:

$$CFM = Q(RT)/c_p(60)p(t_{rm} - t_{sa}) \qquad \text{(E-14-4)}$$

Using standard atmospheric pressure of 14.7 psia, a temperature of -10°F, or 450° Rankine, and a specific heat for air of 0.24 BTU/lbm-hr, this reduces to:

$$CFM = Q(53.35)(450)/(0.24)(60)(14.7)(144)(t_{rm} - t_{sa}) = Q/1.27(t_{rm} - t_{sa})$$

The heat removed is equal to the refrigeration required and at peak load that is 71 tons or 852,000 BTU per hour. The room temperature is -10°F and the supply air temperature is -20°F. With these values the required CFM becomes:

$$CFM = 852{,}000/1.27(-10 - (-20)) = 67{,}087$$

This computed CFM and an assumed static pressure of one and one-half inches of water were used to enter fan curves and determine fan horsepower (0.8 inches across coil, 0.15 inches for filters, 0.26 for dampers, and 0.29 for ducting) (York, 1974:26).

These fan horsepowers were used to calculate the heat added to the refrigerated spaces by the air handlers and to determine the electrical consumption of the air handlers.

Cooling of Product. The cooling of product peak load was computed using a volume of input of new products per hour, the density of the product, and the specific heat of the product and temperature difference. The

equation is below:

$$Q = \rho(vol)c_p(\Delta t) \qquad \text{(E-14-5)}$$

The volume used was five percent of the total volume per hour. This value was divided by two because it was assumed that it would take two hours for the product to reach the design temperature. This was done to obtain a peak load that could be time averaged by ECUBE. As mentioned in the report an average value of density (200 lb/cubic foot) and specific heat (0.03 BTU/lbm) were estimated and a temperature difference of ten degrees were used. The ten degree temperature rise was specified as typical by Mr. Kronholz, Refrigeration Engineer for York. With these values for the freezer the cooling of product load becomes:

$$Q = (8437.5)(200)(0.03)(10) = 506{,}250 \text{ BTU/hr}$$

Refrigeration Systems Cost Comparison. The comparison of refrigeration systems is presented in Tables E-14-1, and E-14-2. The tables compare the life cycle costs of eight systems analyzed for the freezer and cooler area. As previously referenced in the main report, the installed cost and maintenance costs were obtained from the manufacturer, and the electric costs were computed using the inflated energy rate and kilowatt-hours consumed calculated by ECUBE.

Insulation Costs Versus Operating Costs. This section explains the values used to construct the insulation costs versus the operating costs figures in the main report. For both the freezer and cooler, three computer runs were made using ECUBE with everything constant except for the different U values. The annual operating costs and the changes in the costs were computed from the electric consumption computed by ECUBE. The insulation costs were computed for each U value using styrofoam with a thermal

resistance of 4.76 inch-^{o}F per BTUH and the cost was determined from a pricing guide (Craftsman, 1975:205). The values computed for the freezer and cooler are in Table E-14-3. The results have been extrapolated for three additional values for the freezer and four values for the cooler (see Table E-14-3). These values are still accurate because the insulation cost can be computed exactly and the change in operating cost is almost exactly the same as the computed values as long as the same refrigeration system is used.

Total Freezer/Cooler Costs. The costs for the freezer, cooler, and loading dock are listed in Table E-14-4 and E-14-5. The costs are broken into four groups; the building shell costs, the special construction costs, the energy systems cost, and the annual operating and maintenance costs. The building shell costs were computed using cost data from the main warehouse area and are based on 30 foot column spacing, 30 foot roof height, and a 1000 pound per square foot floor loading. The special construction costs are the costs of additional construction needed to convert the building shell to a freezer/cooler area. These costs were based on two pricing guides (Craftsman, 1975)(Means, 1975). The energy systems costs and the annual operating and maintenance costs were taken from the appropriate sections of the main report.

TABLE E-14-1

FREEZER REFRIGERATION SYSTEMS COST

TYPE COST	3-8 CYL. * SCHED. 1	2-12 CYL. SCHED. 1	3-8 CYL. SCHED. 2	2-12 CYL. SCHED. 2
Installed (Capital)	160,000	156,000	160,000	15,600
Installed (Annual)	17,763	17,319	17,763	17,319
Annual Maintenance	14,894	14,600	14,894	14,600
Annual Electric	29,938	30,464	30,124	30,488
Total Annual	62,595	62,383	62,781	62,407

TABLE E-14-2

COOLER REFRIGERATION SYSTEMS COST

TYPE COST	3-6 CYL. * SCHED. 1	2-8 CYL. SCHED. 1	2-8 CYL. SCHED. 2	3-6 CYL. SCHED. 2
Installed (Capital)	182,000	194,000	180,000	182,000
Installed (Annual)	20,205	21,537	19,983	20,205
Annual Maintenance	17,928	18,200	17,650	17,928
Annual Electric	27,628	27,461	28,057	27,653
Total Annual	65,761	67,168	65,690	65,786

*Selected system

TABLE E-14-3

INSULATION COSTS AND OPERATING COST

U VALUE	ANNUAL KWH	OPERATING ANNUAL COST	INCHES OF INSULATION	TOTAL COST	INSULATION ANNUAL COST	TOTAL ANNUAL COST
			FREEZER			
0.01 *	562,412	$24,802	21.0	$144,415	$15,910	$40,712
0.02	601,230	$26,514	10.5	$ 76,320	$ 8,473	$34,987
0.03	640,023	$28,225	7.0	$ 53,640	$ 5,955	$34,180
0.04	678,865	$29,938	5.25	$ 42,300	$ 4,696	$34,634
0.05 *	717,683	$31,650	4.2	$ 35,496	$ 3,940	$35,590
0.06 *	756,501	$33,362	3.5	$ 30,969	$ 3,412	$36,774
			COOLER			
0.03	604,689	$26,667	7.0	$ 93,870	$10,421	$37,088
0.04	615,995	$27,165	5.25	$ 74,025	$ 8,218	$35,383
0.05	626,476	$27,628	4.2	$ 62,118	$ 6,896	$34,524
0.06 *	637,316	$28,108	3.5	$ 54,180	$ 6,015	$34,123
0.07 *	648,156	$28,584	3.0	$ 48,524	$ 5,346	$33,930
0.08 *	658,996	$29,062	2.6	$ 44,270	$ 4,877	$33,939
0.09 *	669,836	$29,540	2.3	$ 40,961	$ 4,512	$34,052

* Interpolated values

TABLE E-14-4

FREEZER/COOLER CAPITAL COSTS ($)

ITEM	FREEZER	COOLER	LOADING DOCK
Building Shell			
Foundation	10,667	21,334	10,857
Column Footings	3,416	6,831	2,403
Walls	49,410	65,880	46,721
Outside Wall Footings	20,258	13,505	40,965
Structural Steel	44,438	88,875	31,205
Roof	15,863	31,725	11,139
Total Capital Cost	146,695	233,436	143,289
Special Construction			
Insulation	43,575	63,758	0
Vapor Barrier (2 Barriers)	9,900	16,200	0
4-Doors, Air Lock (Automatic Actuating)	17,150	16,228	0
2-Air Curtains	482	482	0
Protective Curbing	2,250	3,000	0
Truck And Railroad Car Doors	0	0	14,960
Interior Finish (Portland Cement)	50,738	83,025	0
Dry Fire Protection System	10,688	21,375	0
Floor Finish	16,875	33,750	0
Total Capital Cost	183,496	304,521	14,960

TABLE E-14-4 CONTINUED

ITEM	FREEZER	COOLER	LOADING DOCK
Energy Systems			
Refrigeration Systems	160,000	182,000	0
Lighting Systems	2,885	6,806	5,449
Emergency Lights	1,478	2,956	1,038
Transformer	27,806	30,427	1,601
Total Capital Costs	192,169	222,189	8,088
Total Of Three Capital Costs	522,360	760,146	166,337

TABLE E-14-5

FREEZER/COOLER ANNUAL COSTS ($)

ITEM	FREEZER	COOLER	LOADING DOCK
Yearly Operating Cost	14,256	13,156	1,162
Yearly Maintenance Cost	15,143	18,037	293
Total Annual Cost	87,390	115,582	19,921

APPENDIX W-1

STATEMENT OF WORK

This appendix is included at the end of the report, in its original form, to serve as a point of reference. The design parameters from which GCE-76S worked are included in the basic Statement of Work. The amendments, as negotiated by EATG and GCE-76S, are included behind the Statement of Work. Reference is made to the amendments by use of footnotes. In addition, other items are presented that resulted from further negotiations between EATG and GCE-76S and they are included immediately following the amendments to the Statement of Work.

The pages of this appendix are numbered in the same manner as the original Statement of Work to avoid confusion.

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PREFACE

The following statement of work represents an acceptable compromise between the study needs of the DODMDS study group and the GCE-76S students listed on the cover sheet. It is recognized that this scope may have to be modified as time progresses and as the significant parameters emerge from the study.

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STATEMENT OF WORK

FOR THE

GENERAL WAREHOUSE MODULE

AFIT/GCE-76S DESIGN PROJECT

Section Leader:	Major High	
Members:	Major Alexander	
	Sq Leader Carmichael	
	Captain Craig	
	Captain Inouye	
	Captain Kotti	
	Captain Lay	
	Captain Mansfield	
	Captain Teague	

Civil Engineering/Facilities
Class Advisor,
Head, Mechanics & Engineering
Systems Department,
School of Engineering,
Air Force Institute of Technology

Dr. D. W. Breuer

Chairman, Design and
Modernization Task Group,
Department of Defense Materiel
Distribution Systems Study
Group

Colonel Phillip M. Ozenick

12 March 1976

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I. Background

A. The Department of Defense Materiel Distribution System (DODMDS) Study Group was formed for the purpose of recommending improvements which will effectively and economically support the services' requirements in both peacetime and under mobilization. The specific purpose of DODMDS is to review and analyze current materiel distribution system processes, and identify future peacetime and mobilization support requirements world wide. They will recommend alternatives to optimally integrate, consolidate, and standardize distribution system functions and facilities within the fifty states where it is clearly beneficial in terms of response and cost.

As a part of the overall mission of the DODMDS, the Distribution Center Design and Modernization Task Group (DAMTG)[1] is specifically charged with the responsibility of developing an implementation plan for the modernization of existing facilities and constructing new supply distribution depots. DAMTG[1] has developed a design concept of a modern storage facility in the form of a general warehouse module. Data relative to the warehouse module will be part of a computer model to forecast the optimum use of the entire governmental supply system.

B. The AFIT School of Engineering conducts a Graduate Civil Engineering/Facilities program which is designed to develop in the student the ability to define technical problems, to make engineering analysis, and to solve problems as an Air Force/DOD Civil Engineer. As part of the Civil Engineering/Facilities program, the students select a project which draws upon previous course work to solve a

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significant Air Force or DOD problem. The students work under a team of faculty members over two academic quarters (twenty weeks). The current class, GCE-76S, has 15 members and is divided into two sections. After considering the scope of the effort involved, section one, consisting of nine members of the class, has elected to undertake the General Warehouse Module Project presented by DAMTG.[1]

II. Problem

The group will develop a facility concept for the general warehouse module from which construction, operation, and maintenance cost curves can be extrapolated. The facility cost data is an essential input parameter for the DODMDS computer models which optimize and simulate the DOD materiel distribution system. A general warehouse module is constructed for the storage of general types of materiel, to include small, medium, and bulk items. Some materiel requires special environmental control. The building structure must be adaptable to use for storage and handling of of a wide mix of commodity types.

III. Scope

The design of the general warehouse module will be developed for the conditions of the Norfolk, Va. area. This is not to imply that this location will remain in the final DODMDS findings, but merely represents typical environment and engineering considerations. To the extent that research time permits, the influence on design and cost of seismic conditions for the level found in the Oakland area will be included. The development of the facility concept

will be divided into four areas: design parameters, civil engineering, mechanical engineering, and electrical engineering. These areas are listed below.

A. Design Parameters

1. Total enclosed floor area will be 50 acres.
2. Ten acres will be designed as an operating area. This area will be used for distribution processing including receiving, preservation, packaging, set and unit assembly, packing, shipping, container assembly and manufacture, and maintenance support.
3. Cost analysis and building design will be limited to the gross outside building line plus five feet.
4. Design will be limited to proven state-of-the-art technology.
5. All variables adjudged to be significant as a result of this study effort will be subjected to sensitivity analysis.
6. All cost factors will be shown in units of 1,000 cubic feet.

B. Civil Engineering

1. Floor to ceiling heights of 30 to 60 feet in the storage area will be considered in logical increments. The ceiling height for the 10 acres of operating area will be 30 feet.
2. Column spacing will be investigated over a minimum range of 60-120 feet in logical increments and optimized. A span length of 60 feet will be considered minimum acceptable while the 120 feet can be exceeded if required for optimization.[2]
3. Floor loading will be considered at a minimum of 1,000

pounds per square foot throughout the entire facility. Cost sensitivity in increments of 2,000 pounds per square foot should be provided to a level of 8,000.[3]

4. Columns and roof supports in the operating area will be designed with and without additional loads for overhead conveyor systems at 180 pounds per linear foot with suspension at 10 foot centers.
5. Cost per linear foot of crane support will be determined for indoor and outdoor overhead bridge cranes with a total gross load of 300,000 pounds.
6. Interior and exterior wall sections will be determined for each ceiling height analyzed. Interior walls will be non load-bearing, fire walls.
7. An area of 4.3 million cubic feet[4] secure storage including associated operating area will be designed i.e., small arms.
8. Volume flow of rain run-off will be determined.
9. Analysis of train facilities within the operating area will be made.[5]

C. Mechanical Engineering

1. Heating equipment will be provided for the entire facility although it may not normally be used. The heating plant will have the capability of maintaining 55°F minimum temperature in the storage segment and 65°F in the operating segment of the facility on a design cold day. The heating plant must be capable of multi-fuel operation.

2. Maximum temperatures must not exceed 120°F in the storage areas.
3. Solar energy will be considered in the design of the environmental control systems.
4. The building will be zoned so that the temperature within zones may be individually controllable.
5. Ten acres of the storage area will require a relative humidity not to exceed 50 percent.
6. One million cubic feet of chill space will be provided. Equipment will be designed to maintain the entire space at 32°F and a maximum of 50 percent relative humidity. A cost analysis for operating the chill space at incremental temperatures between 32°F and 50°F will be included.[6] Freezer will be maintained at 0°F.[7] A cost trade off will be made between chiller operating costs and ceiling height.[8]
7. A trade off will be made between insulation costs and environmental control costs for the structure, freezer and chill space.
8. Within the operations area Occupational Safety and Health Act (OSHA) environmental standards will be applied.
9. Environmental equipment design and operating costs will be analyzed for the operating area.
10. Costs for fire protection using the various types of sprinkler systems to include the investigation of foam and/or wetting agents will be determined.

D. Electrical Engineering

1. The study team will design and analyze the primary power distribution network.[9]
2. Loads for the environmental mechanical equipment will be generated by the study.
3. Results will include a load study and short circuit analysis of the primary power network.[10]
4. The electrical power distribution system will provide for connection of a portable power generating system.
5. OSHA standards for general warehouse lighting will be met for all areas. Trade offs will be made between various lighting system costs and lumens output. Evenness of lighting will be evaluated.
6. Charging of materials handling equipment will be at a central point.

E. Items that will not be considered.

1. Types and costs of mechanical docks will not be investigated.
2. No design or costs for material handling equipment will be included.
3. An environmental assessment report will not be provided.

IV. Assumptions

A. First costs associated with construction and startup of the building (omit supply processing equipment) will be amortized based on a 25 year useful life for the structure with zero salvage value. Economic analysis will follow Department of Defense economic analysis procedures, based on 1976 prices.

B. Federal land is available; therefore, the cost of land will not affect the study.

C. Current DOD construction constraints and policies are not limiting factors to the study.

D. Study results will be limited to state-of-the-art in facility construction.

E. The necessary data base for accurate modeling of warehouse operations necessary for determining building operating and maintenance cost is available through study and survey of similar military and civilian facilities.

F. Physical characteristics of material to be stored is available through DAMTG.[1]

G. Peak receiving period will occur within the range from 0800 to 1400 hours with heaviest load at 0900.

H. Peak shipping period is at 1400 hours over the operating period of 0800 to 1630.

V. Standards

The warehouse will be designed using several codes for construction. The major codes are: ASHRAE Handbook of Fundamentals, OSHA standards, National Electric Code, AISC Manual of Steel Construction, National Uniform Building Code, and American Concrete Institute Code, National Fire Protection Association Handbook.

VI. Approach

The group has been divided into three teams: civil, electrical, and mechanical. Each team has a faculty advisor. Meetings with the advisors will help keep the team efforts channeled towards a

solution.

A. The Civil Engineering team will analyze warehouse construction to determine the most suitable structure for providing required environmental protection at least cost per cubic foot. Cost analysis will include initial construction costs and yearly maintenance costs over an assumed building life of 25 years. The analysis will follow the following sequence.

1. Determine environmental loads.
2. Analyze roof structure for incremental span lengths. The minimum span length investigated will be 60 feet.[2]
3. Select an upper limit for span lengths.
4. Design columns to support roof loads. Parameters to be varied include the following:
   a. Column location.
      (1) Corner Section

      Corner sections will be defined as the corner column plus the adjacent columns required for wind bracing.

      (2) Exterior Wall Section

      An exterior wall section will contain two adjacent columns within the exterior wall which are not associated with the corner sections.

      (3) Interior Sections

      Interior sections will include four adjacent interior columns located on the corners of a rectangle. These columns will be independent of exterior wall sections.

   b. Incremental column height from 30 feet to 60 feet.

5. Design exterior wall sections. Parameters to be varied include the following:
   a. Column spacing
   b. Column height
6. Design interior wall sections. Parameters to be analyzed include the following:
   a. Column height
   b. Column spacing
   c. Fire protection requirements
   d. Environmental control requirements. These will be received as inputs from the Mechanical Engineering Group.
7. Research typical soil conditions for the Norfolk, Va. area.
8. Design column foundations for each type and size of column analyzed.
9. Design warehouse floor to hold from 1,000 to 8,000 lbs per square foot.[3]
10. Integrate roof, wall, column, and foundation costs for each column spacing and ceiling height studied.
11. Develop a cost analysis per 1,000 cubic feet as a function of ceiling height and column spacing.

B. Mechanical Engineering

An outline of the design and analysis approach to be taken by the Mechanical Engineering Team follows. This study will be directed at determining the equipment requirements, operating procedures, and initial and operational costs involved in the environmental control within a 50 acre general warehouse module.

1. Determine internal environmental requirements
2. Select building zones.
3. Model zones

   Parameters to be varied include:

   a. "U" values
   b. Color of roof and walls
   c. Height of ceiling
   d. Weight of structure
   e. Orientation and location of zones within the building
4. Calculate heating point, cooling point, and solar loads for each zone model.
5. Obtain weather data tape.
6. Model internal equipment, people, and lighting loads for each zone.
7. Model facility and equipment operating schedules.
8. Integrate building total heating and cooling load requirements for hourly intervals over one year period for each modeled condition.
9. Select optimum building orientation, internal floor plan, and construction parameters to minimize total annual costs.
10. Model equipment selection
    a. Multi-fuel operation
    b. Solar applications
11. Analyze equipment operation
    a. Staging
    b. Fuel selection

12. Determine total costs - initial and operating for each model.

13. Select optimum operating system and cost.

In addition to the environmental analysis, the Mechanical Engineering Team will conduct a study of applicable procedures and requirements for fire protection and fire protection systems. This study will interface with findings and results from the Civil Engineering Team. The approach taken for analyzing fire protection will proceed as follows:

1. Survey current practices for fire protection in modern warehouse facilities.
2. Determine building fire characteristics.
3. Research fire protection standards.
4. Determine fire protection systems available and costs.
5. Analyze application of available systems to the general warehouse module.
6. Select the most cost effective system.

   Results will be expressed in dollars per 1000 cubic feet for each type zone within the building.

C. Electrical Engineering

The proposed design approach to be followed by the Electrical Engineering Team is as follows:

1. Determine illumination standards and requirements for each building zone.
2. Research available illumination systems and current practices for application.

3. Analyze costs of installation and operation for differing systems within each building zone.
4. Select lighting systems and provide Mechanical Engineering Team with watts per square foot data.
5. Determine general purpose electrical loads (codes, standards, current practice).
6. Model material handling equipment system loads.
7. Obtain mechanical environmental equipment loads from the Mechanical Engineering Team.
8. Analyze emergency electrical requirements.
9. Design primary power distribution network and emergency backup system.
10. Conduct and analyze load flow study.
11. Conduct short circuit analysis and plan circuit protection.[10]
12. Determine system costs and total energy requirements cost.

VII. Support

A. DAMTG[1] will provide reproduction capability for documents resulting from this agreement.

B. DAMTG[1] will arrange and fund field trips. A total of four are envisioned: J.C. Penney and Sears Distribution Centers and the Defense Construction Supply Center (DCSC) in Columbus, Ohio and the New Cumberland Army Depot, Harrisburg, Pa. Where TDY and travel funds are necessary the group will be limited to four students.

C. Subject to written justification by students, DAMTG[1] will provide automatic data processing over and above that provided by AFIT.

Initial evaluations indicate that the study group will require access to the American Gas Association's program ECUBE. This program is distributed through the CDC Cybernet System. Initial estimate indicates the ECUBE support will Cost $3,000.[11]

D. GCE-76S students are responsible for any typing and drafting support they require.

E. All AFIT facilities are available as normally provided for student project work of this nature which includes library and limited computer support.

F. Operating schedules necessary for modeling warehouse operations will be provided by DAMTG.[1]

G. Results of a design study on the applications of solar energy to warehouse operation conducted at Tobyhanna Army Depot, Pa. will be provided [12] by DAMTG.[1]

H. Equipment electrical loads and emergency power requirements must be provided by DAMTG.[1]

VIII. Schedule

A. The scheduling of the GCE-76S project must coincide with the requirements of the School of Engineering and DAMTG[1] to meet significant DODMDS milestones. The selection of this project by the GCE-76S students will help meet a portion of the DAMTG[1] task of conceptual design alternatives to be completed by 2 August 1976.

B. The GCE-76S class will meet the following milestones:

1. Statement of work - 1 March 76

The statement of work is an AFIT requirement which will

contain project definition, individual team responsibilities, and beginning conceptual work.

2. Status report - 29 April 76

   To assess organization progress, and analytical approach being taken to resolve stated problem.

3. Status report - 3 July 76

   The status report is an AFIT requirement which is a check to see if most of the design and analytical work has been completed.

4. Initial DAMTG[1] report - 2 Aug 76

   The initial DAMTG[1] report is a submission of construction costs per cubic foot and operations and maintenance costs per cubic foot.

5. Initial draft report - 16 Aug 76

   This is an AFIT and DAMTG[1] requirement to review and assess the project.

6. Oral defense of project - 26 Aug 76 (tentative)

7. Final report - 13 Sep 76

   Students will incorporate AFIT faculty and DAMTG[1] comments.

IX. Points of Contact

To facilitate communications between AFIT and DAMTG,[1] the points of contact for the DAMTG[1] and AFIT will be:

1. Mr. Joseph Mucci

   AFLC/DSXE/AV 787-7475

2. Mr. Thomas Vrba

   Chief of Depot Operation Division

   DARCOM Packaging Storage & Containerization Center

   Tobyhanna Army Depot

   AV 247-9262/3

3. Captain Robert S. Tripp

   AFIT/ENS/AV 787-5758

4. Dr. D. W. Breuer

   AFIT/ENB/AV 785-3517

5. Major J. T. High

   AFIT/ENA/AV 785-5533

AMENDMENTS TO STATEMENT OF WORK

1 DAMTG has been redesignated as EATG (Engineering Analysis Task Group).

2 The column spacing was changed to include an analysis of one column spacing, 60 feet by 60 feet, in the mechanized and general storage areas. In the operating area, a reduced column spacing of 36 feet by 60 feet was analyzed to allow for the suspended conveyor loads.

3 The design floor loads were not changed but an investigation of the use of piles was requested by EATG.

4 The secure storage volume was changed to approximately 1.1 million cubic feet.

5 No analysis of train facilities within the operating area was conducted but train facilities were designed along two specified perimeter walls.

6 The design temperatures for the cooler were 32°F, 40°F, and 50°F. (The term "chiller" was replaced by the term "cooler".)

7 The design temperature for the freezer was changed to -10°F.

8 No cost trade off was made between cooler operating costs and ceiling height.

9 The electrical distribution system was specified by EATG to be a primary selective-secondary selective system.

10 No short circuit analysis of the primary power network was accomplished.

11 The ECUBE computer support was increased from $3000 to $9500.

12 No design study of the applications of solar energy conducted at Tobyhanna Army Depot, Pennsylvania was provided since the preliminary analysis of the potential use of solar energy by GCE-76S was more comprehensive.

Other design parameters negotiated by EATG and GCE-76S.

a. Backup power was defined by EATG to be the power required for a normal workday operation spread over 24 hours to provide normal material throughput operation.

b. EATG requested basic research in the area of Energy Monitoring and Control Systems (EMCS) to include the cost of monitoring points, hardware, and software.